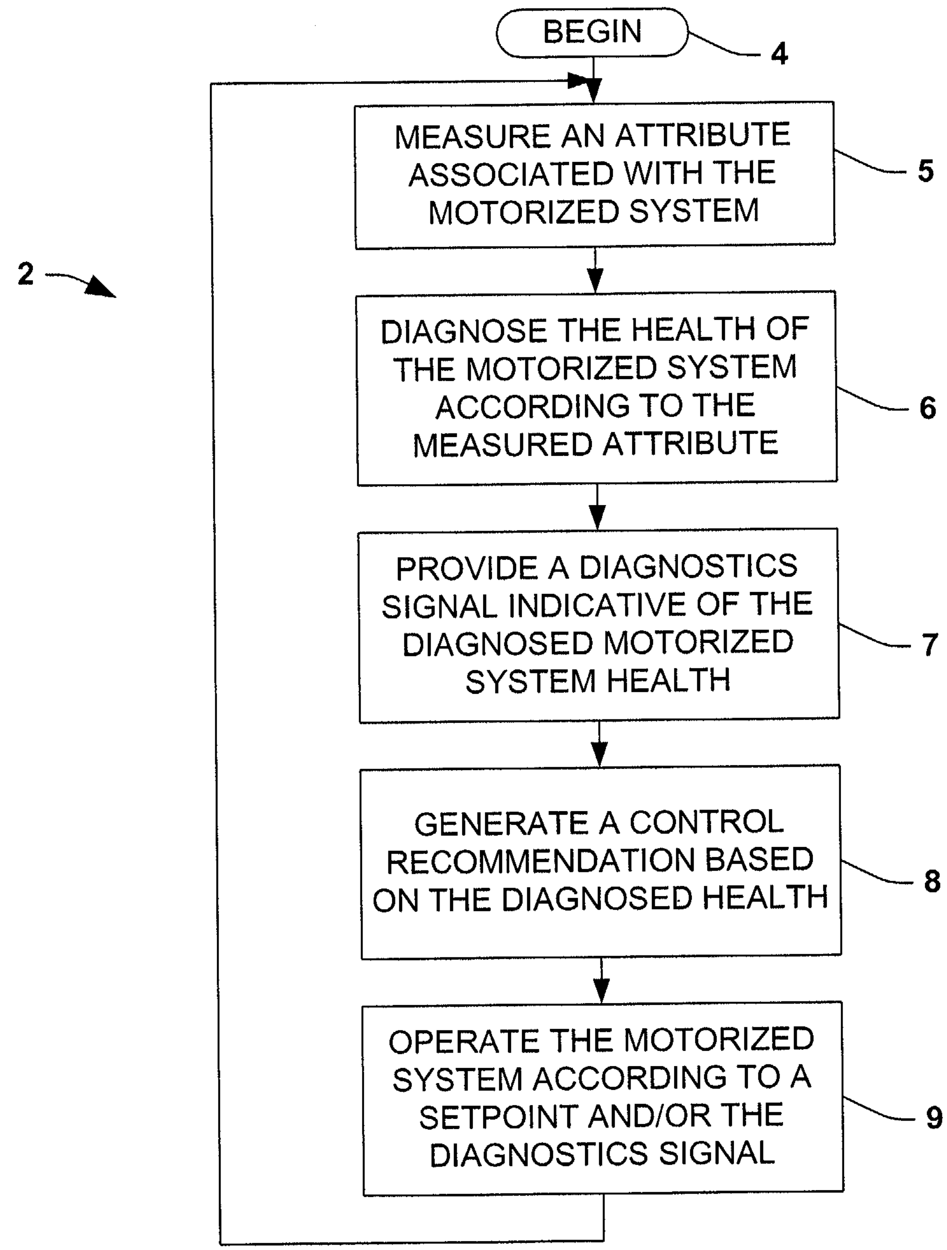

BEGIN
4
MEASURE AN ATTRIBUTE ASSOCIATED WITH THE MOTORIZED SYSTEM
5
DIAGNOSE THE HEALTH OF THE MOTORIZED SYSTEM ACCORDING TO THE MEASURED ATTRIBUTE
6
PROVIDE A DIAGNOSTICS SIGNAL INDICATIVE OF THE DIAGNOSED MOTORIZED SYSTEM HEALTH
7
GENERATE A CONTROL RECOMMENDATION BASED ON THE DIAGNOSED HEALTH
8
OPERATE THE MOTORIZED SYSTEM ACCORDING TO A SETPOINT AND/OR THE DIAGNOSTICS SIGNAL
9
2

FIG. 1

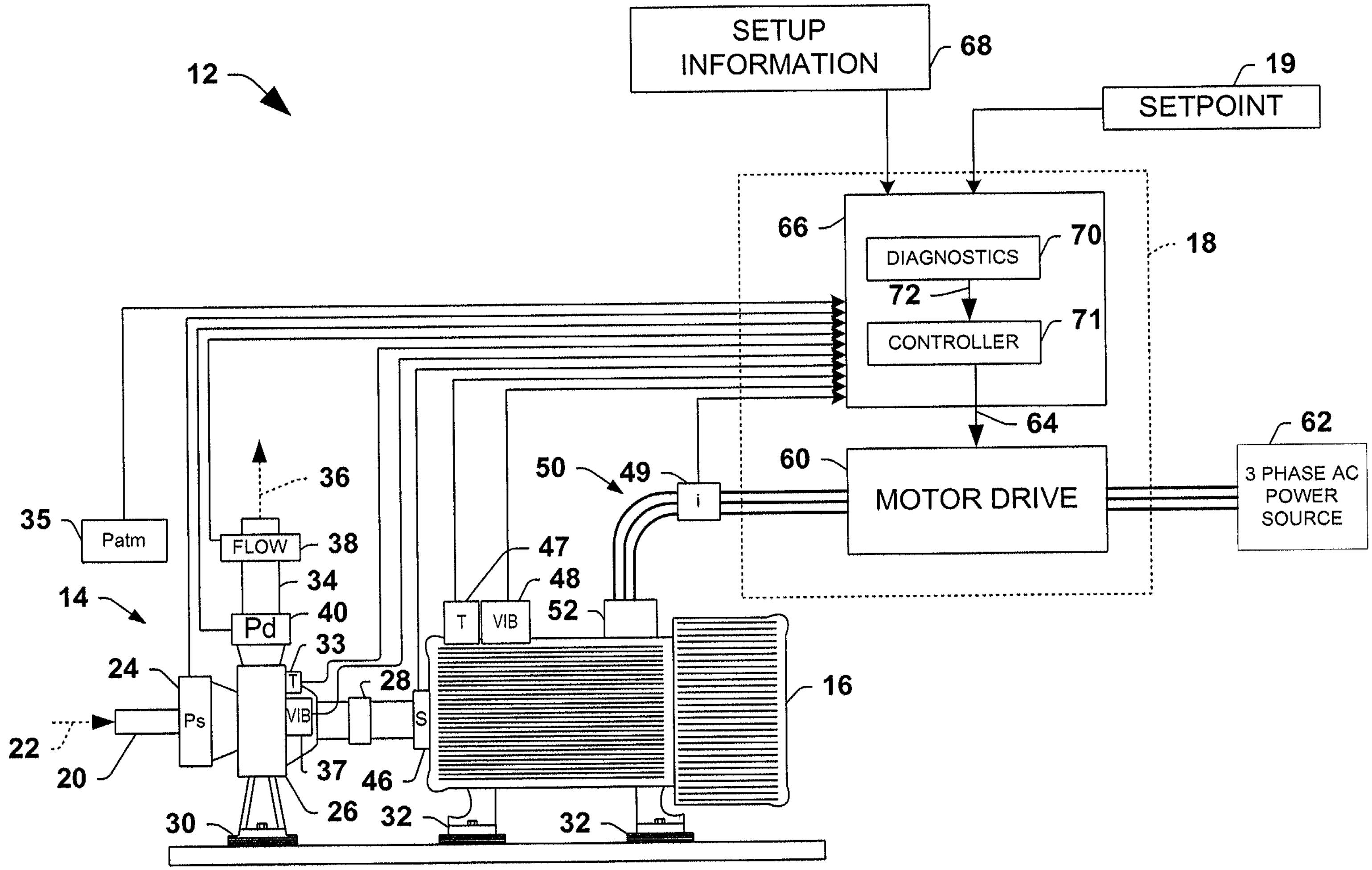

SETUP INFORMATION
68
SETPOINT
19
12
66
DIAGNOSTICS
70
72
CONTROLLER
71
18
64
60
MOTOR DRIVE
62
3 PHASE AC POWER SOURCE
50
49
i
36
35
Patm
FLOW
38
34
14
Pd
40
33
T
VIB
47
48
52
24
28
16
Ps
S
22
20
37
46
26
30
32
32

FIG. 2a

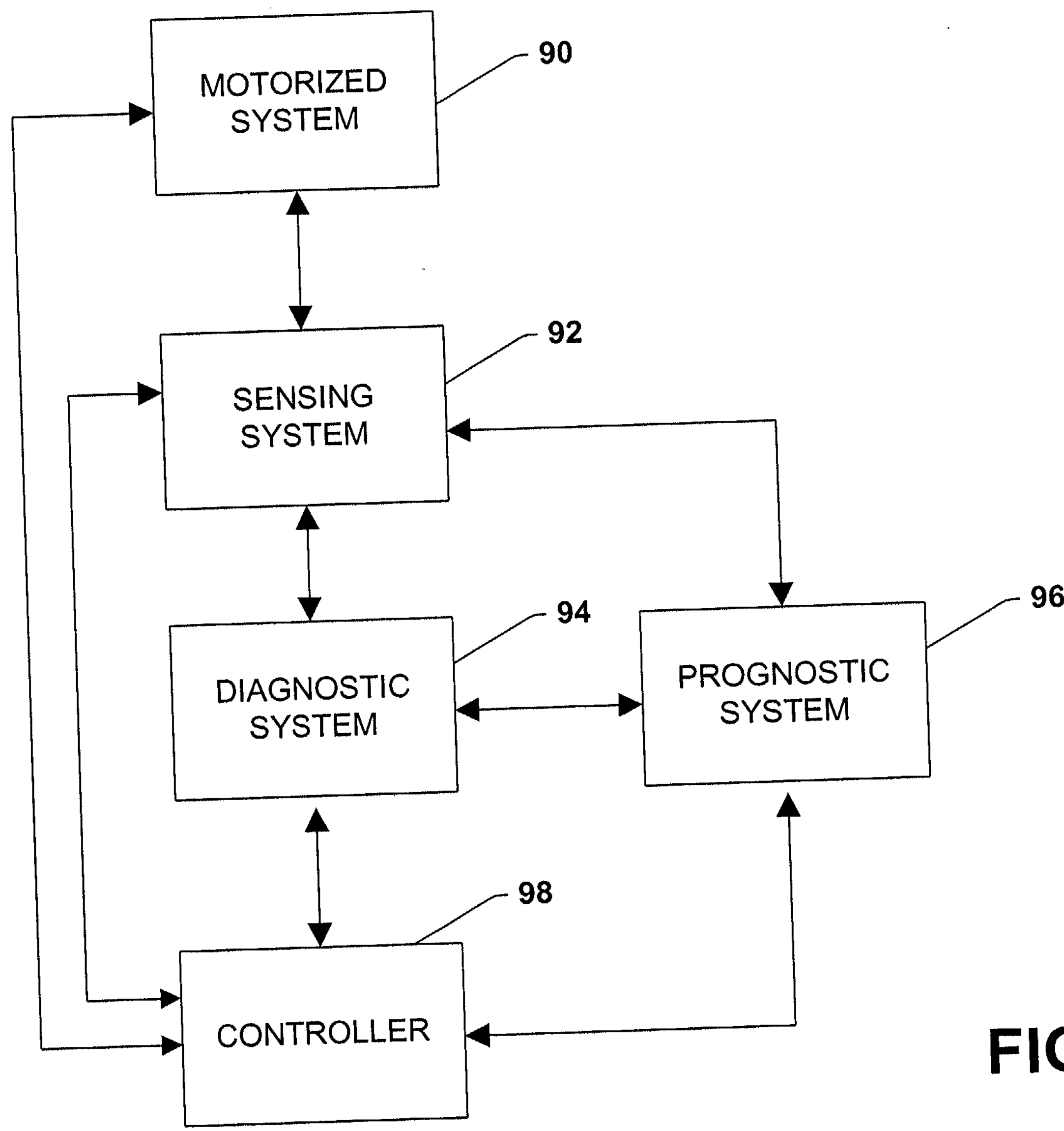
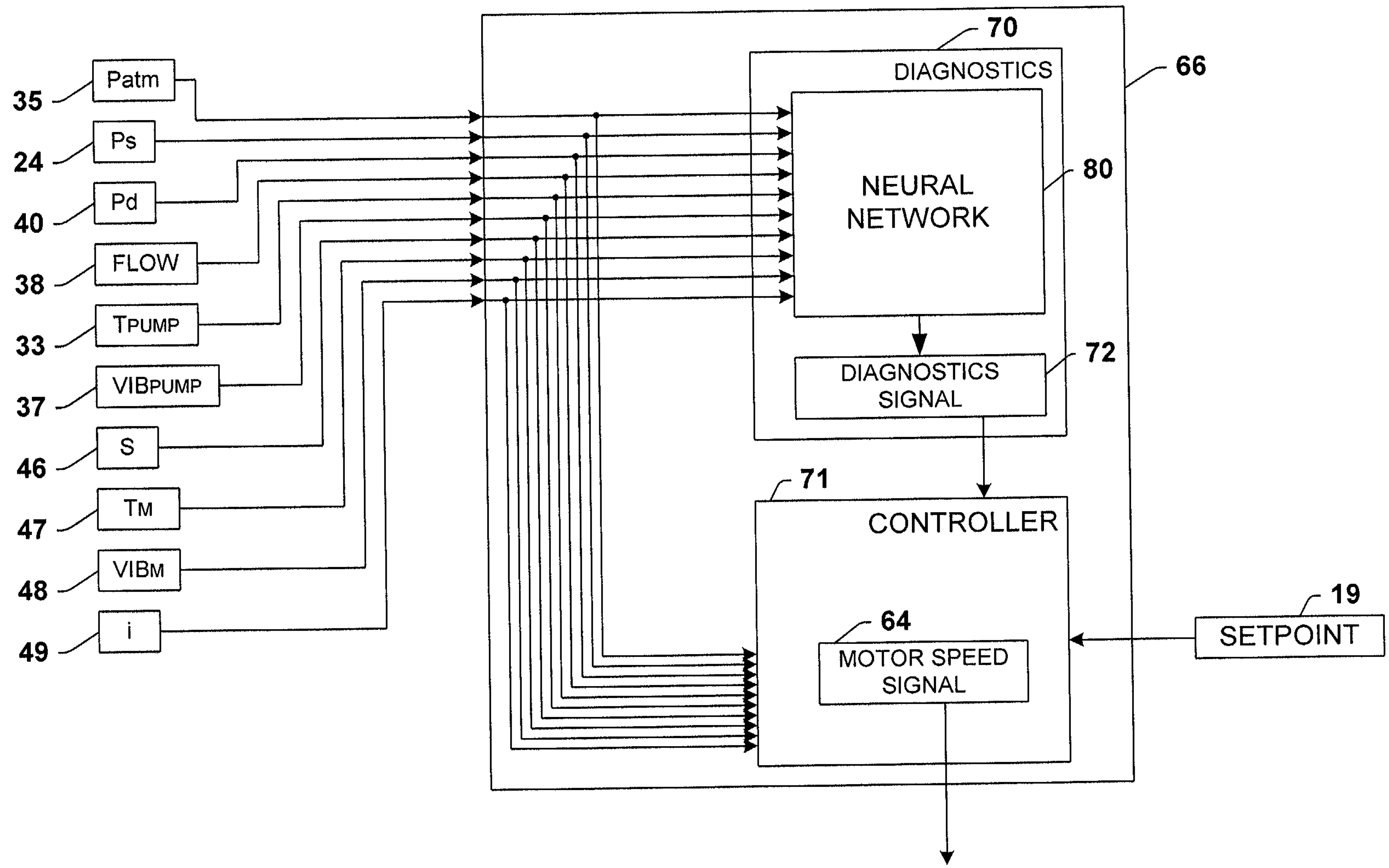
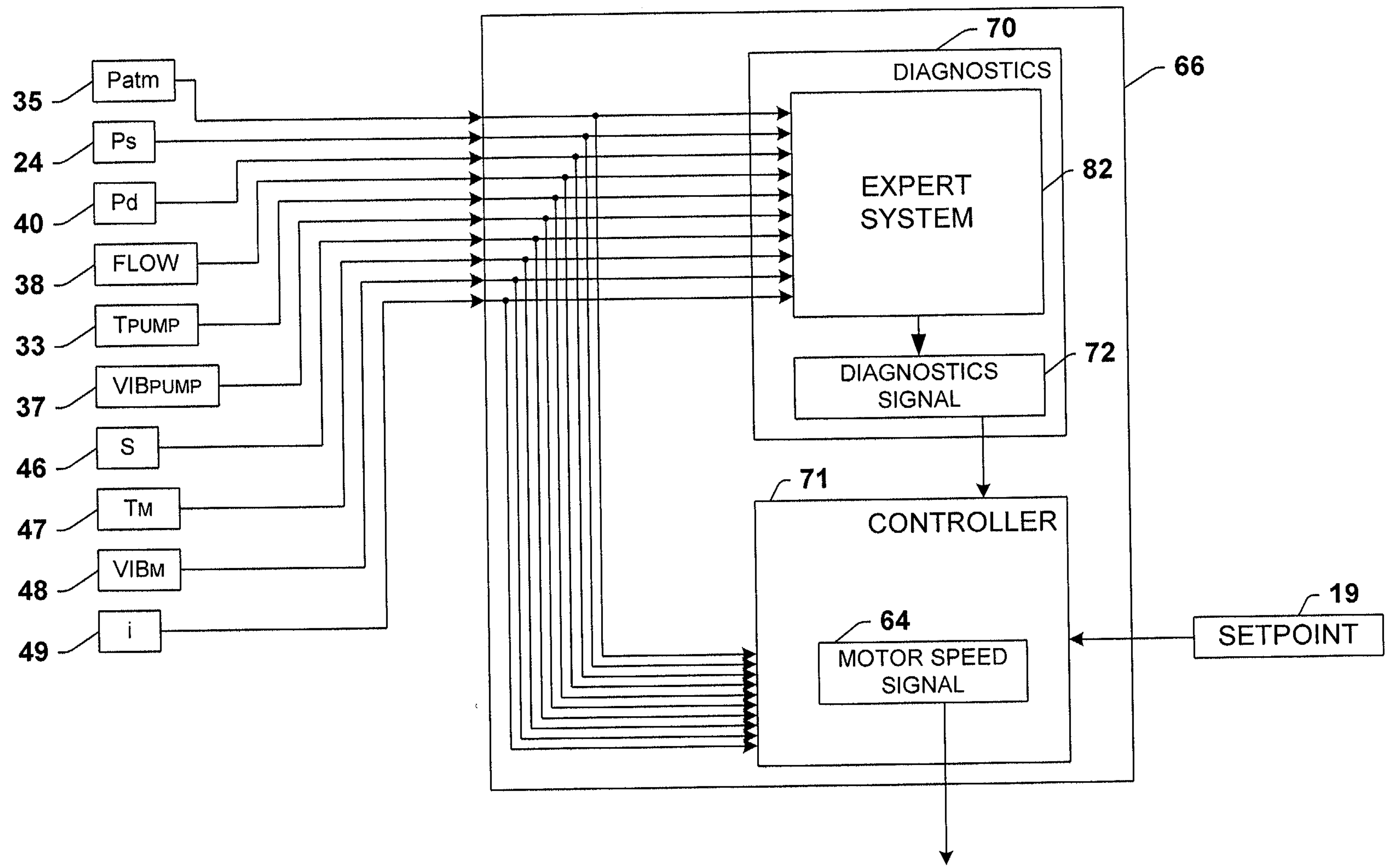

MOTORIZED SYSTEM
90
SENSING SYSTEM
92
DIAGNOSTIC SYSTEM
94
PROGNOSTIC SYSTEM
96
CONTROLLER
98

FIG. 2b



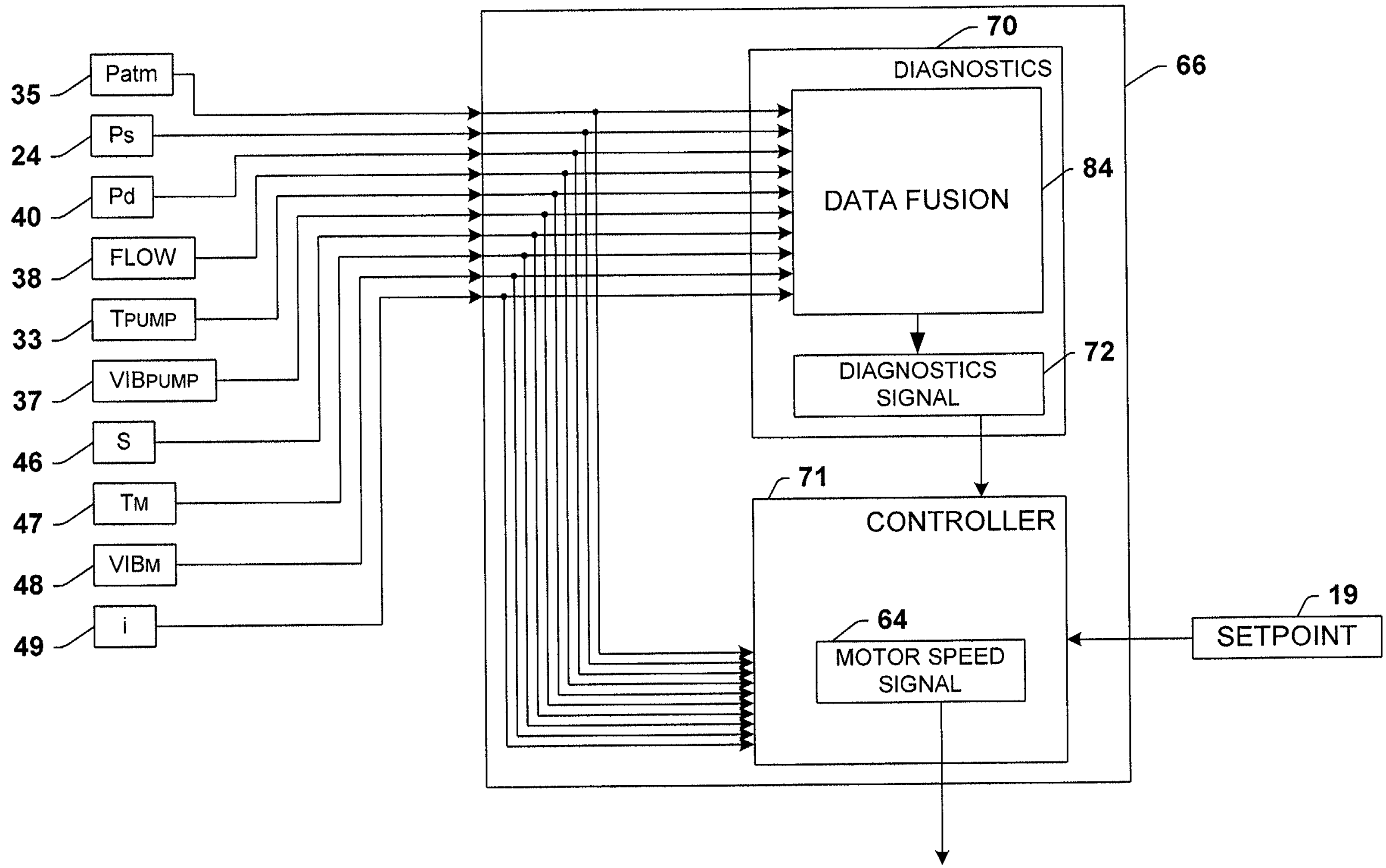
35
Patm
24
Ps
40
Pd
38
FLOW
33
TPUMP
37
VIBPUMP
46
S
47
TM
48
VIBM
49
i
66
70
DIAGNOSTICS
80
NEURAL NETWORK
72
DIAGNOSTICS SIGNAL
71
CONTROLLER
64
MOTOR SPEED SIGNAL
19
SETPOINT

FIG. 3



35
Patm
24
Ps
40
Pd
38
FLOW
33
TPUMP
37
VIBPUMP
46
S
47
TM
48
VIBM
49
i
66
70
DIAGNOSTICS
82
EXPERT SYSTEM
72
DIAGNOSTICS SIGNAL
71
CONTROLLER
64
MOTOR SPEED SIGNAL
19
SETPOINT

FIG. 4



35
Patm
24
Ps
40
Pd
38
FLOW
33
TPUMP
37
VIBPUMP
46
S
47
TM
48
VIBM
49
i
66
70
DIAGNOSTICS
84
DATA FUSION
72
DIAGNOSTICS SIGNAL
71
CONTROLLER
64
MOTOR SPEED SIGNAL
19
SETPOINT

FIG. 5

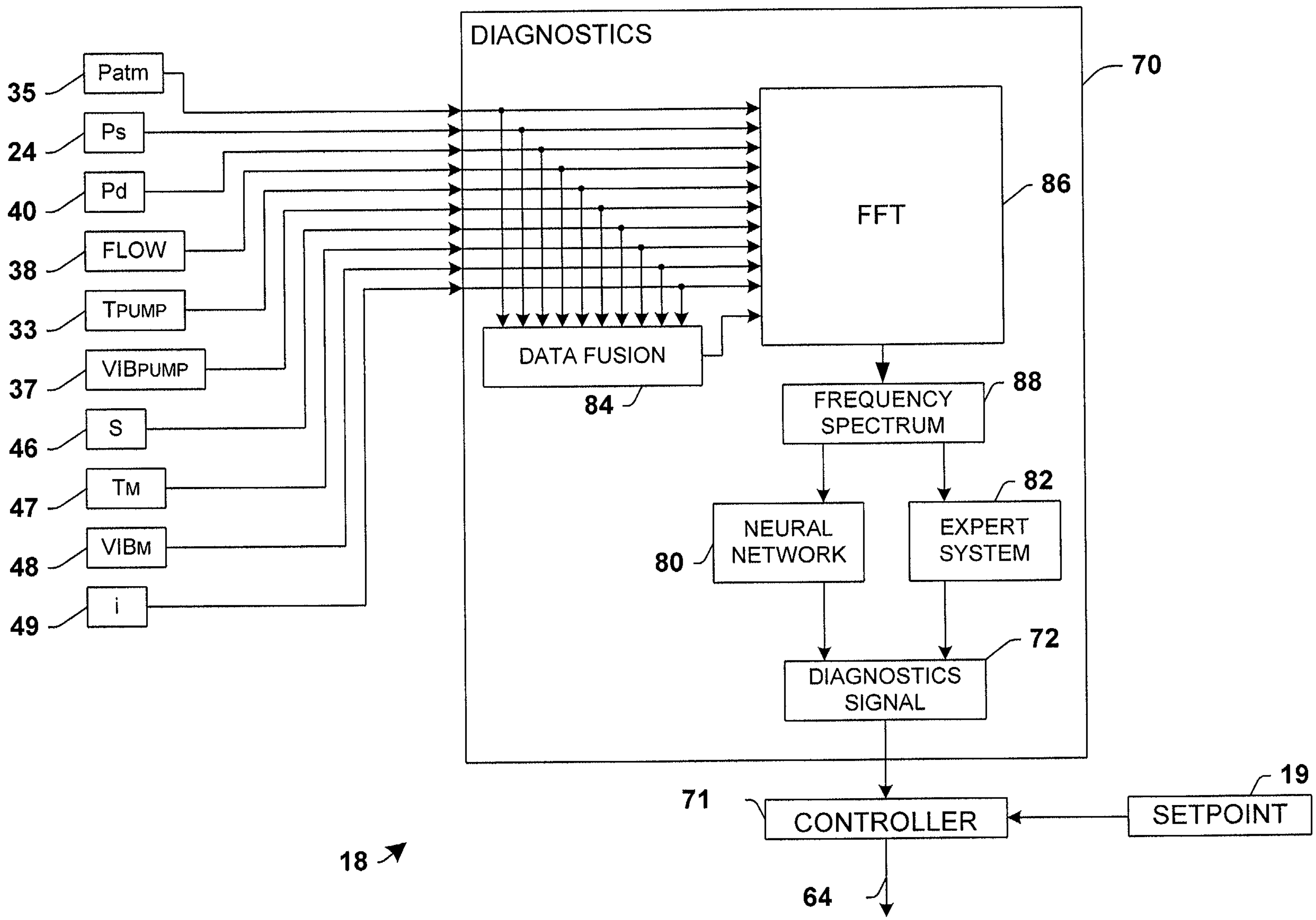
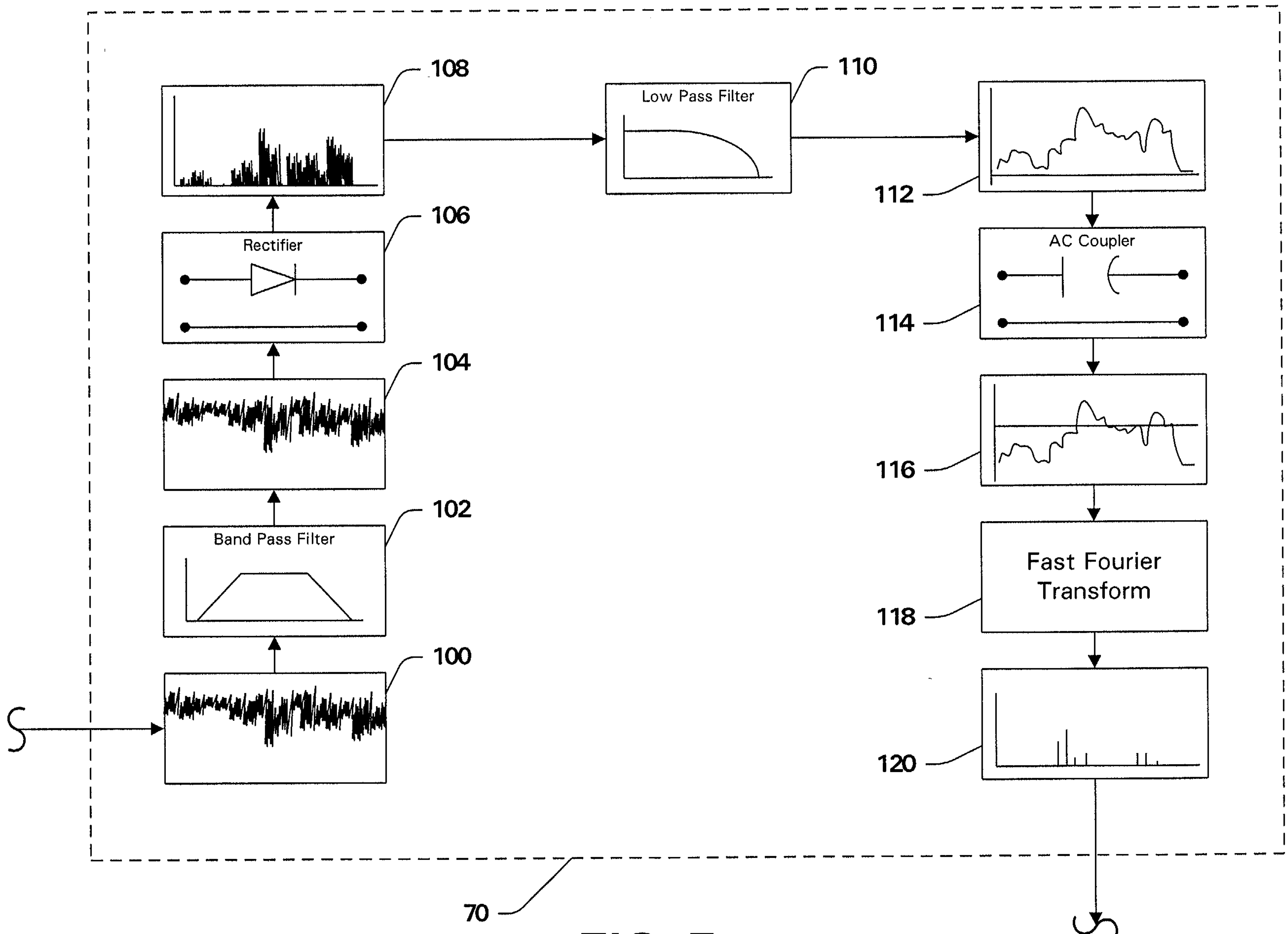

DIAGNOSTICS
70
Patm
35
Ps
24
Pd
40
FLOW
38
TPUMP
33
VIBPUMP
37
S
46
TM
47
VIBM
48
i
49
FFT
86
DATA FUSION
84
FREQUENCY SPECTRUM
88
NEURAL NETWORK
80
EXPERT SYSTEM
82
DIAGNOSTICS SIGNAL
72
CONTROLLER
71
SETPOINT
19
64
18

FIG. 6



108
Low Pass Filter
110
106
Rectifier
104
102
Band Pass Filter
100
112
AC Coupler
114
116
Fast Fourier Transform
118
120
70

FIG. 7

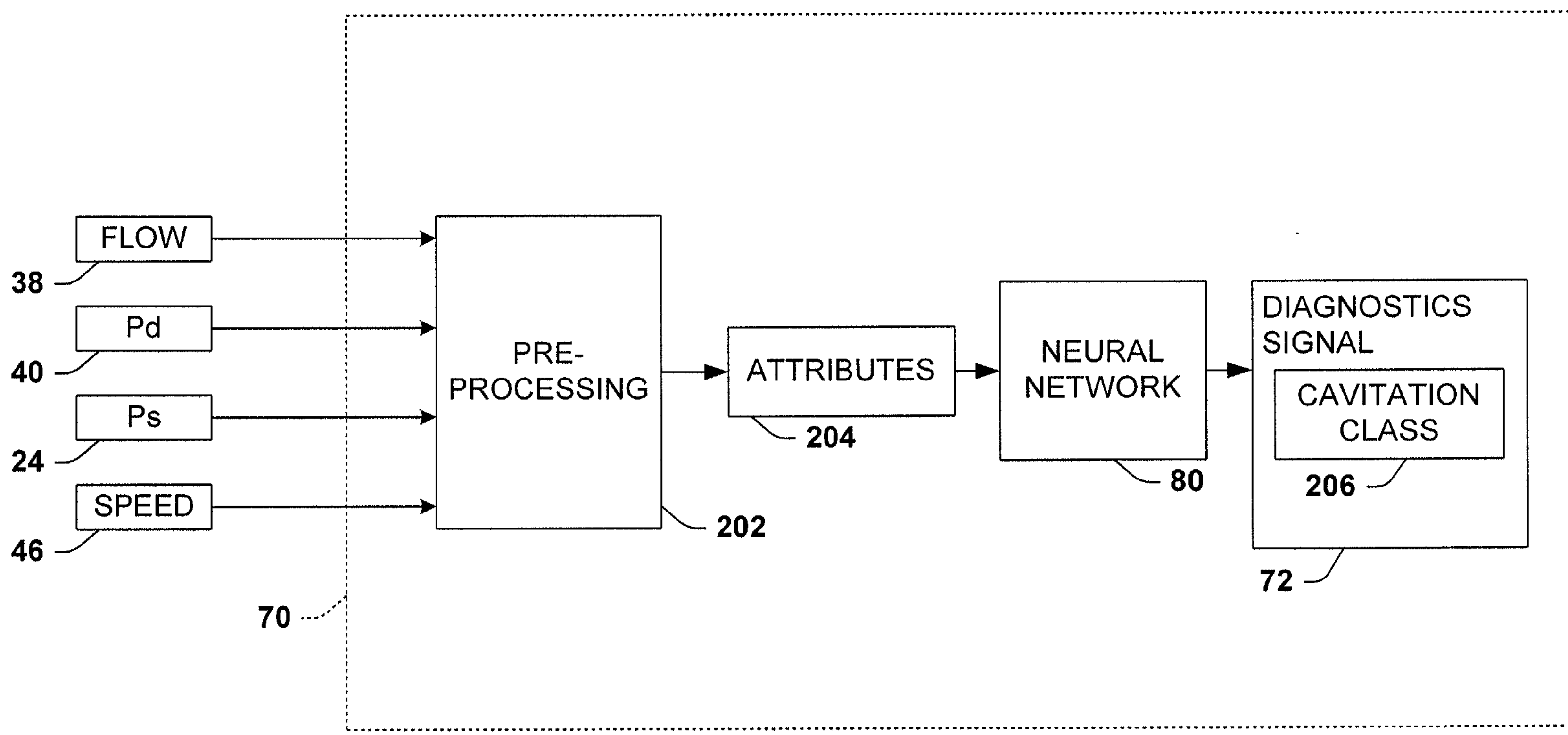

FLOW
Pd
Ps
SPEED
38
40
24
46
70
PRE-
PROCESSING
202
ATTRIBUTES
204
NEURAL
NETWORK
80
DIAGNOSTICS
SIGNAL
CAVITATION
CLASS
206
72

FIG. 8

DIAGNOSTICS SIGNAL

206

CLASS 0	normal; no cavitation
CLASS 1	incipient cavitation; mainly balance hole cavitation
CLASS 2	medium cavitation; mainly vane cavitation
CLASS 3	full cavitation; large amount of bubbles on the suction eye but no surging
CLASS 4	surging cavitation; full blown cavitation with surging

72

FIG. 9

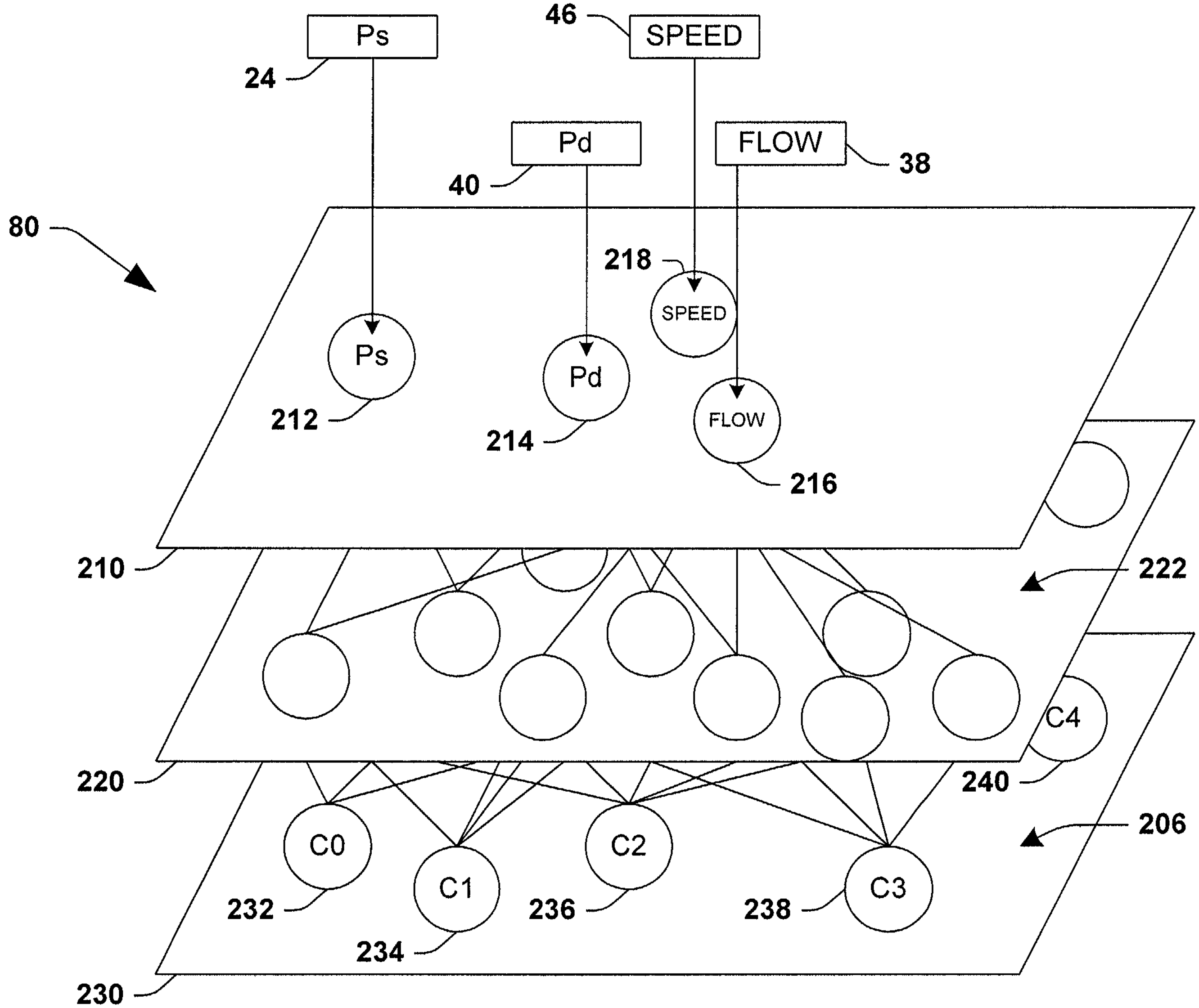

Ps
24
SPEED
46
Pd
40
FLOW
38
80
218
SPEED
Ps
212
Pd
214
FLOW
216
210
222
220
C4
240
206
C0
232
C1
234
C2
236
C3
238
230

FIG. 10

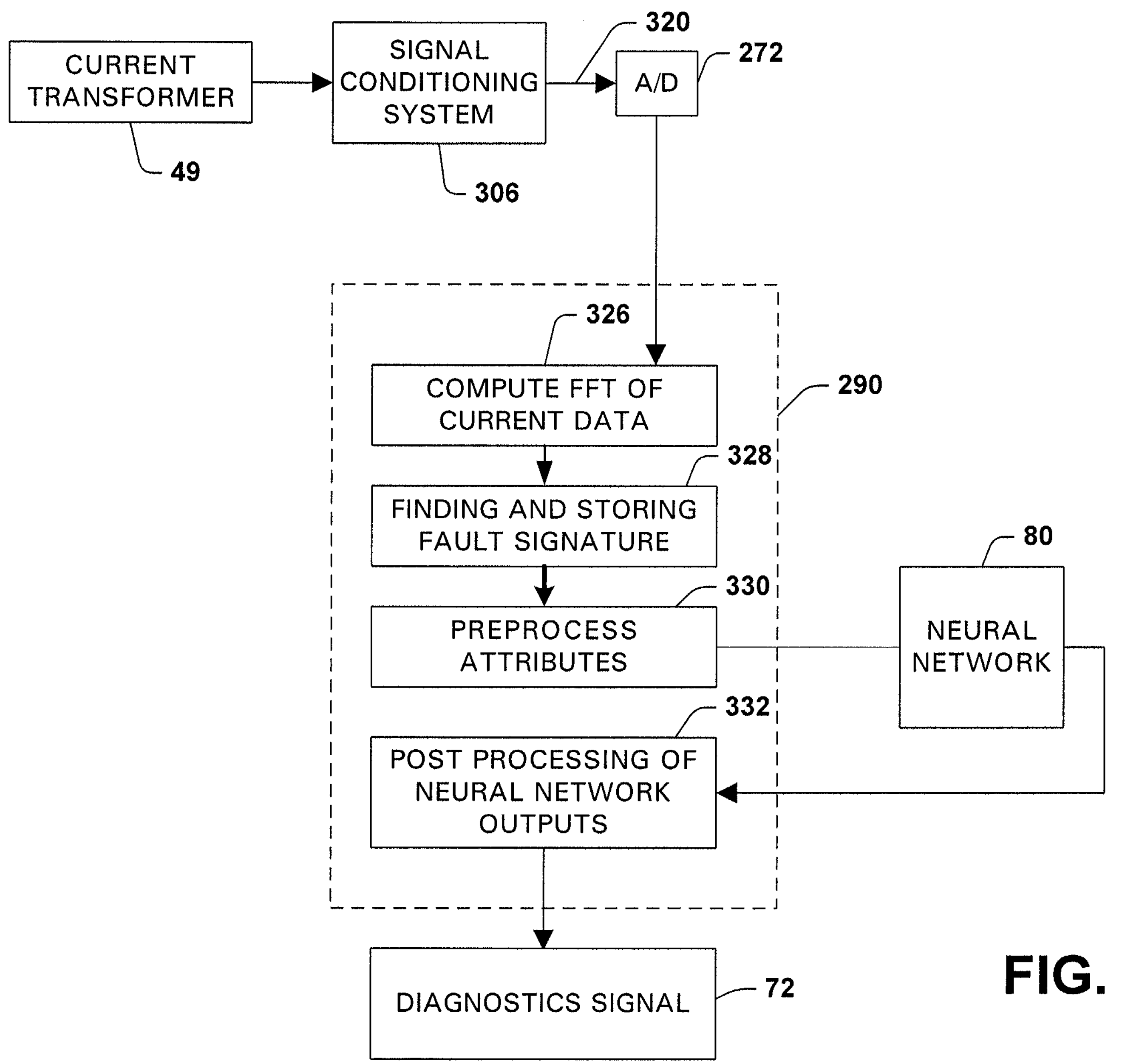

CURRENT TRANSFORMER
49
SIGNAL CONDITIONING SYSTEM
306
320
A/D
272
326
COMPUTE FFT OF CURRENT DATA
290
328
FINDING AND STORING FAULT SIGNATURE
330
PREPROCESS ATTRIBUTES
80
NEURAL NETWORK
332
POST PROCESSING OF NEURAL NETWORK OUTPUTS
DIAGNOSTICS SIGNAL
72

FIG. 11

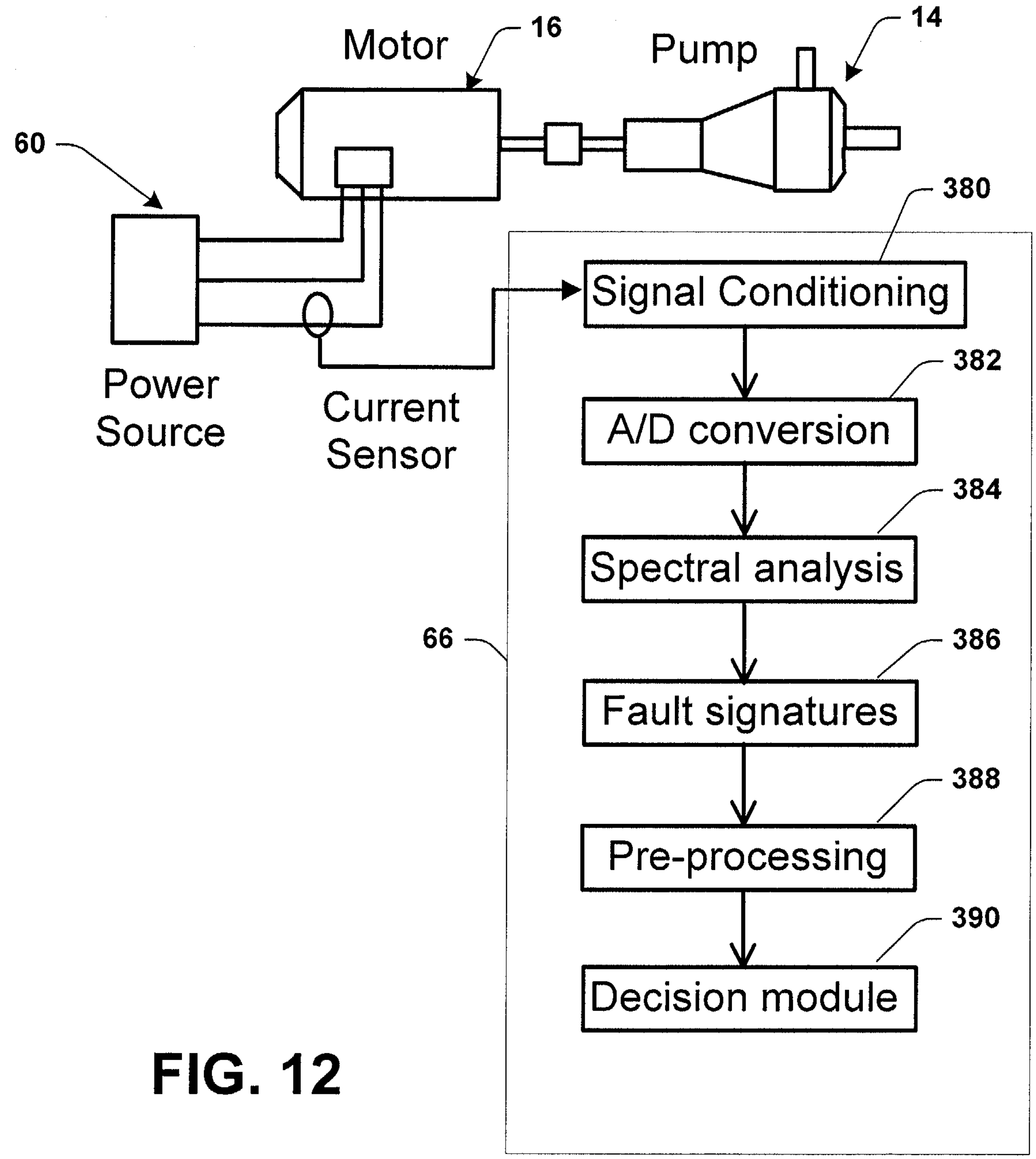

Motor
16
Pump
14
60
380
Signal Conditioning
Power
Source
Current
Sensor
382
A/D conversion
384
Spectral analysis
66
386
Fault signatures
388
Pre-processing
390
Decision module

FIG. 12

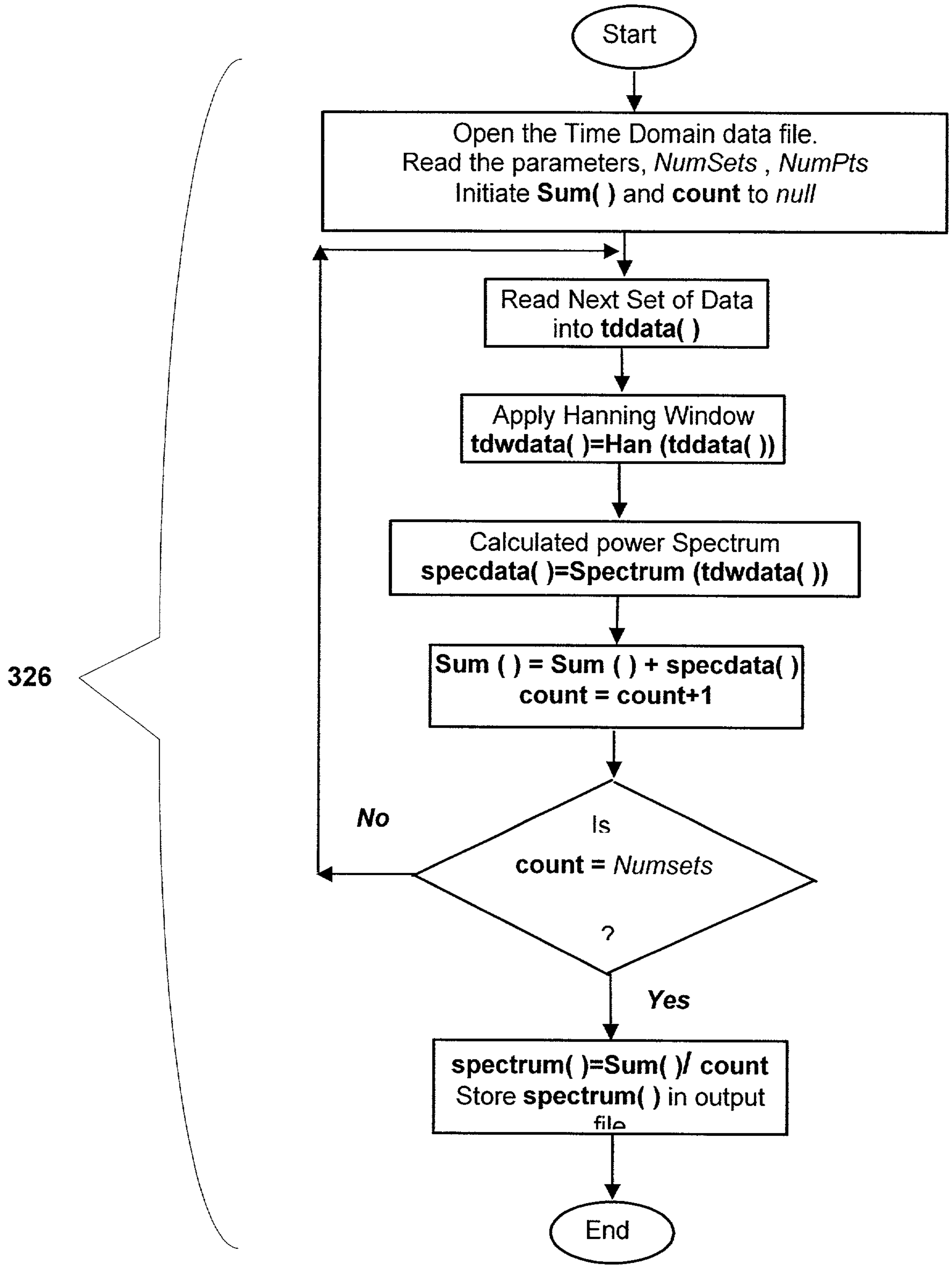

Start
Open the Time Domain data file.
Read the parameters, NumSets , NumPts
Initiate Sum( ) and count to null
Read Next Set of Data into tddata( )
Apply Hanning Window
tdwdata( )=Han (tddata( ))
Calculated power Spectrum
specdata( )=Spectrum (tdwdata( ))
Sum ( ) = Sum ( ) + specdata( )
count = count+1
Is count = Numsets ?
No
Yes
spectrum( )=Sum( )/ count
Store spectrum( ) in output file
End
326

FIG. 13

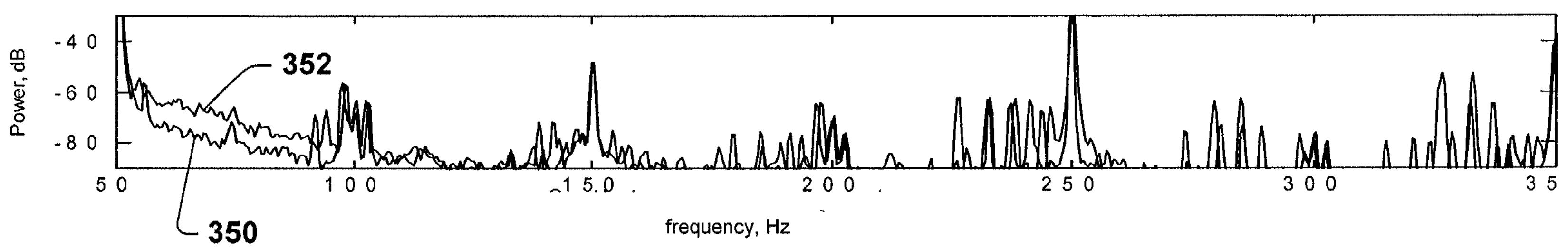


Fig. 14a

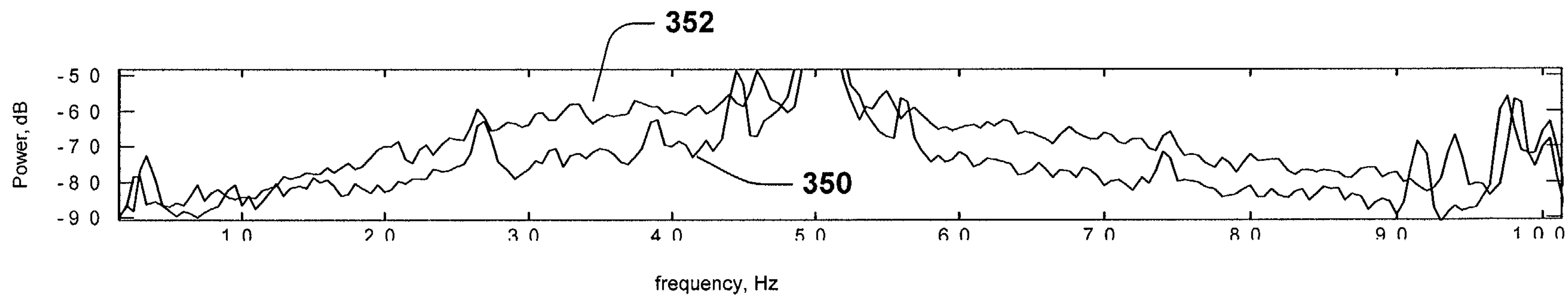


Fig. 14b

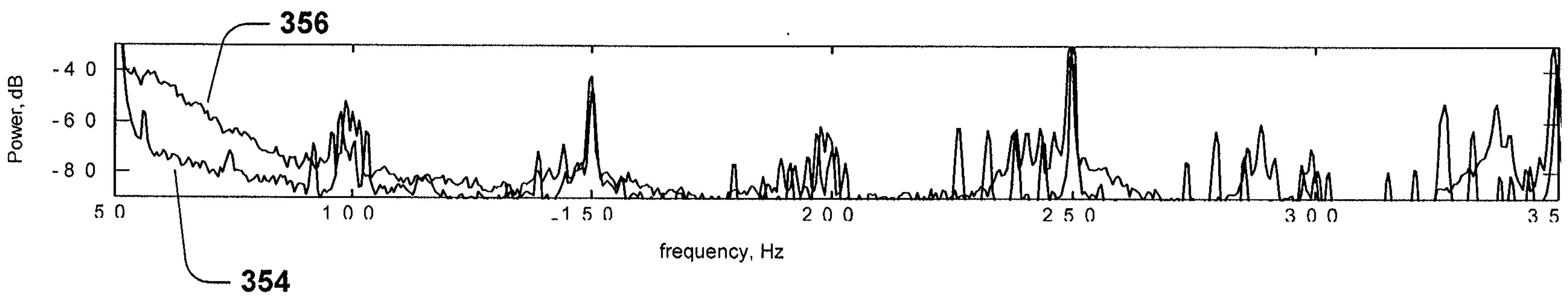


Fig. 14c

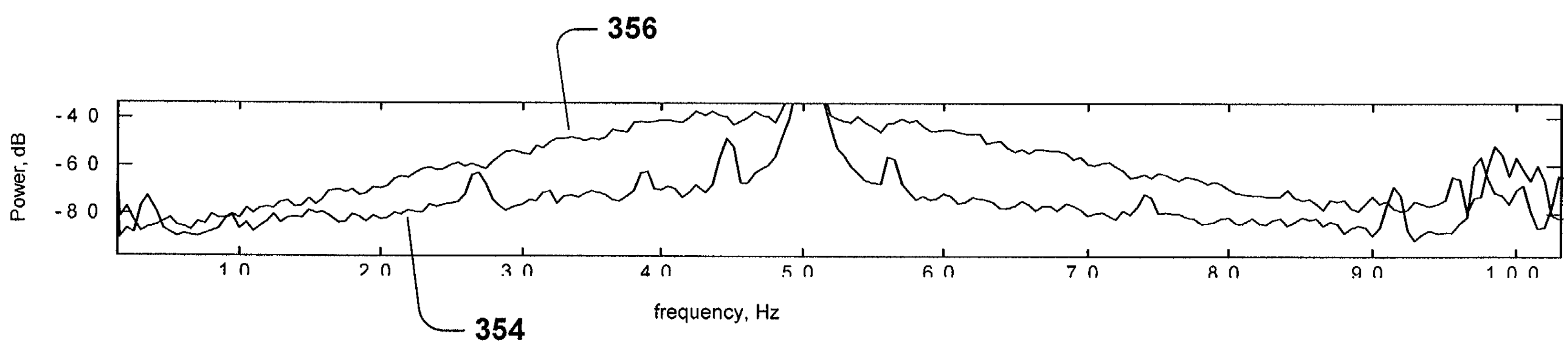


Fig. 14d

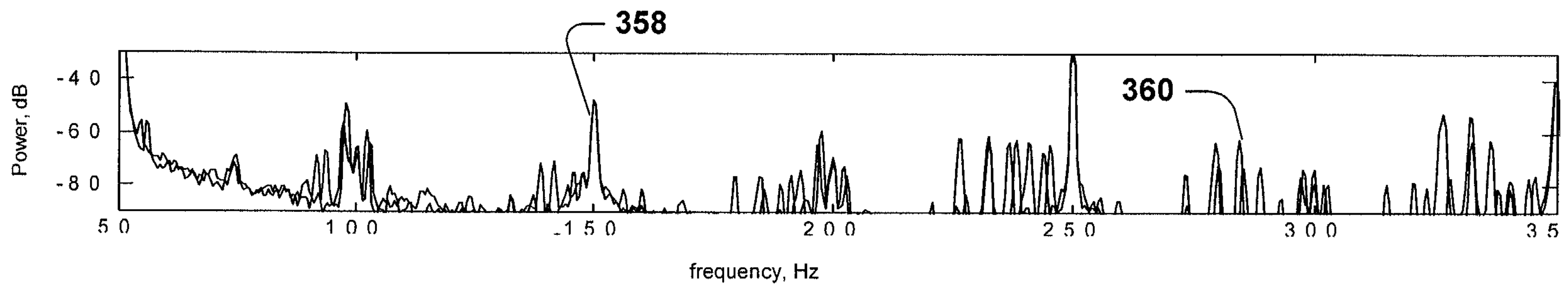


Fig. 14e

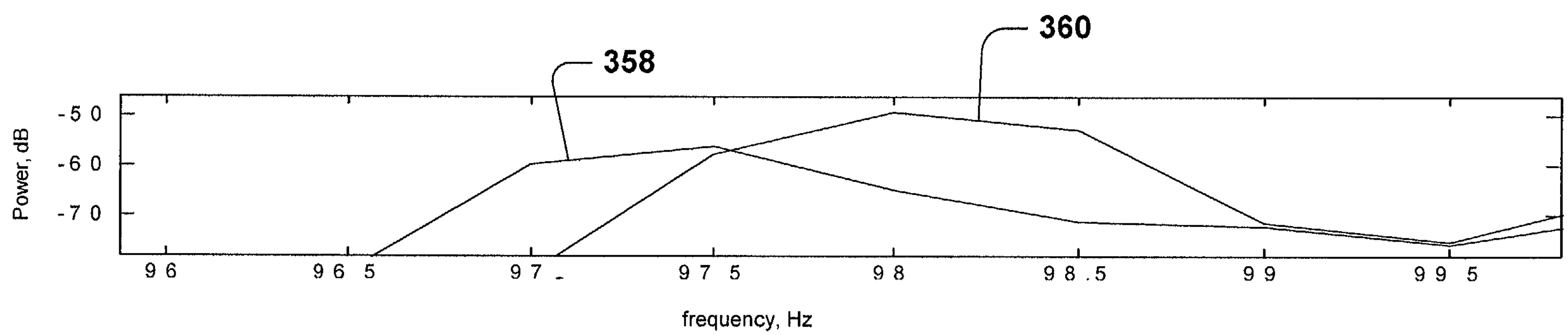


Fig. 14f

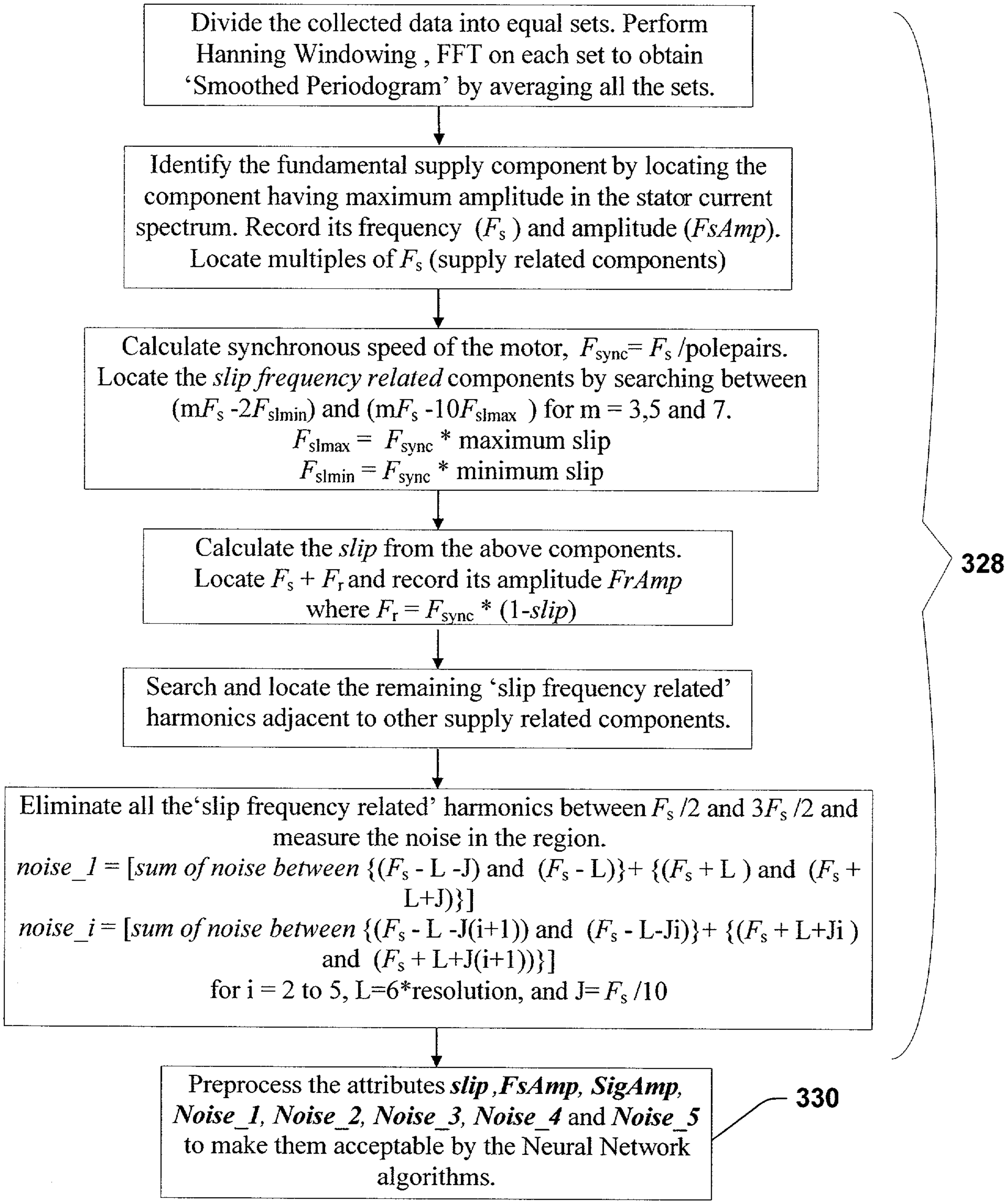
400

402

f_0	f_1	f_2	f_3	f_4	•	•	•	f_n	
A_3	A_{34}	A_{67}	A_{78}	A_{84}	•	•	•	A_K	HEALTHY PUMP
A_{34}	A_{-68}	A_{-90}	A_{-65}	A_{45}	•	•	•	A_H	PUMP FAULT 1
A_{56}	A_{45}	A_{45}	A_{56}	A_{78}	•	•	•	A_X	PUMP FAULT 2
A_{-23}	A_{45}	A_7	A_{90}	A_{12}	•	•	•	A_Z	PUMP FAULT 3
A_{67}	A_{36}	A_3	A_{45}	A_{47}	•	•	•	A_X	PUMP FAULT 4
A_{78}	A_{67}	A_{12}	A_{67}	A_{37}	•	•	•	A_C	PUMP FAULT 5
A_{234}	A_{27}	A_{478}	A_{24}	A_{127}	•	•	•	A_Q	PUMP FAULT 6
A_{-98}	A_{78}	A_{26}	A_{12}	A_{128}	•	•	•	A_B	PUMP FAULT 7
A_{26}	A_{96}	A_{83}	A_{56}	A_{234}	•	•	•	A_M	PUMP FAULT 8
A_4	A_{32}	A_{187}	A_{56}	A_{34}	•	•	•	A_I	PUMP FAULT 9
A_0	A_{16}	A_{73}	A_{76}	A_{33}	•	•	•	A_E	PUMP FAULT N-1
A_{75}	A_{17}	A_{45}	A_{69}	A_{44}	•	•	•	A_Q	PUMP FAULT N

404

FIG. 14g



Divide the collected data into equal sets. Perform Hanning Windowing , FFT on each set to obtain 'Smoothed Periodogram' by averaging all the sets.
Identify the fundamental supply component by locating the component having maximum amplitude in the stator current spectrum. Record its frequency (F_s) and amplitude (*FsAmp*). Locate multiples of F_s (supply related components)
Calculate synchronous speed of the motor, $F_{sync} = F_s$ /polepairs. Locate the *slip frequency related* components by searching between ($mF_s - 2F_{slmin}$) and ($mF_s - 10F_{slmax}$) for m = 3,5 and 7.
$F_{slmax} = F_{sync}$ * maximum slip
$F_{slmin} = F_{sync}$ * minimum slip
Calculate the *slip* from the above components. Locate $F_s + F_r$ and record its amplitude *FrAmp* where $F_r = F_{sync} * (1 - slip)$
Search and locate the remaining 'slip frequency related' harmonics adjacent to other supply related components.
Eliminate all the 'slip frequency related' harmonics between $F_s/2$ and $3F_s/2$ and measure the noise in the region.
noise_1 = [*sum of noise between* {(F_s - L -J) and (F_s - L)}+ {(F_s + L) and (F_s + L+J)}]
noise_i = [*sum of noise between* {(F_s - L -J(i+1)) and (F_s - L-Ji)}+ {(F_s + L+Ji) and (F_s + L+J(i+1))}]
for i = 2 to 5, L=6*resolution, and J= F_s/10
Preprocess the attributes ***slip*** **,*FsAmp*, *SigAmp*, *Noise_1*, *Noise_2*, *Noise_3*, *Noise_4*** and ***Noise_5*** to make them acceptable by the Neural Network algorithms.
328
330

FIG. 15

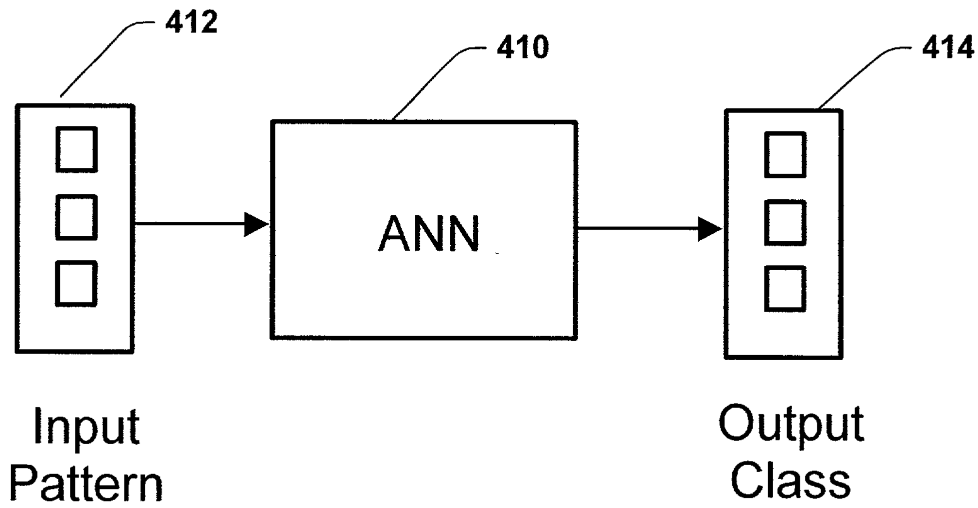

412
410
414
ANN
Input
Pattern
Output
Class

Fig. 16

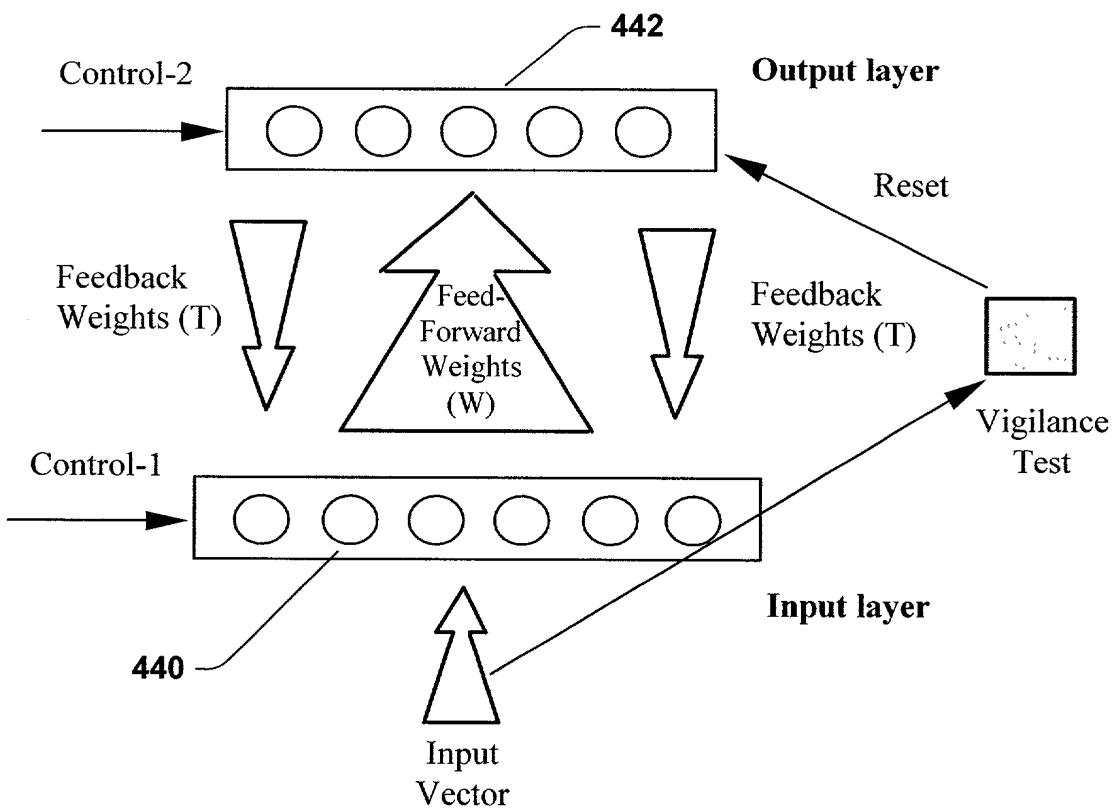

442
Control-2
Output layer
Reset
Feedback
Weights (T)
Feed-
Forward
Weights
(W)
Feedback
Weights (T)
Vigilance
Test
Control-1
Input layer
440
Input
Vector

Fig. 17

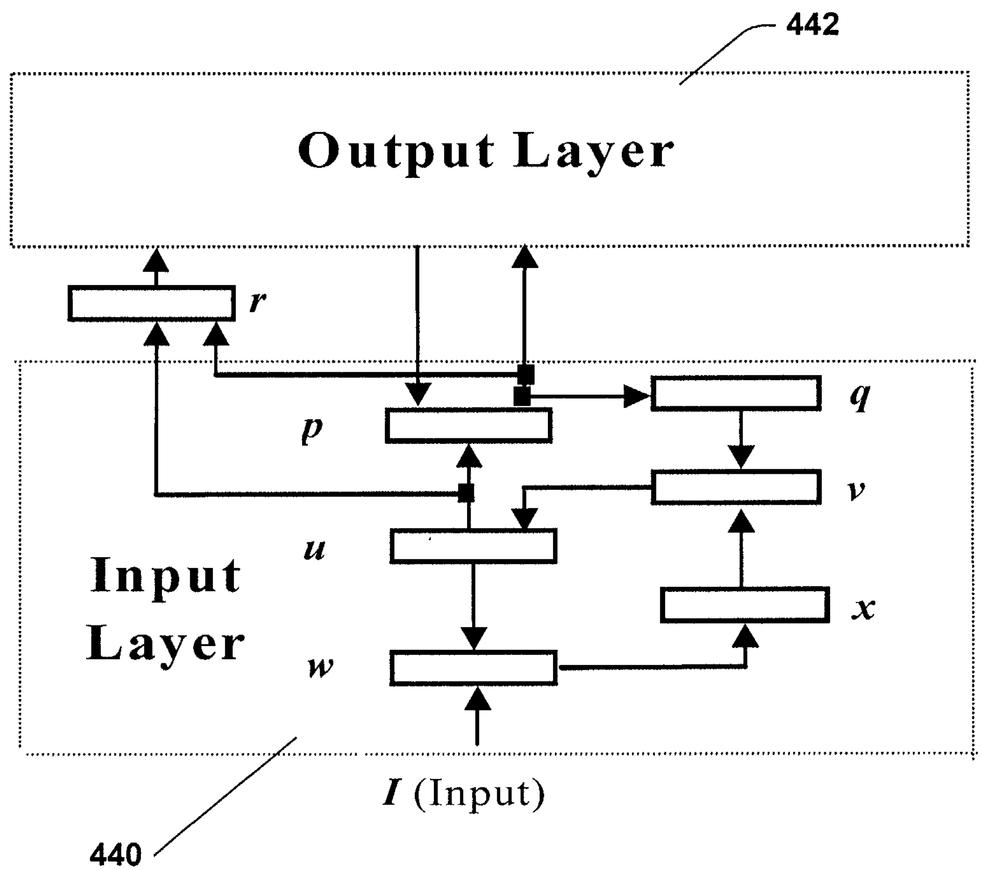


Fig. 18

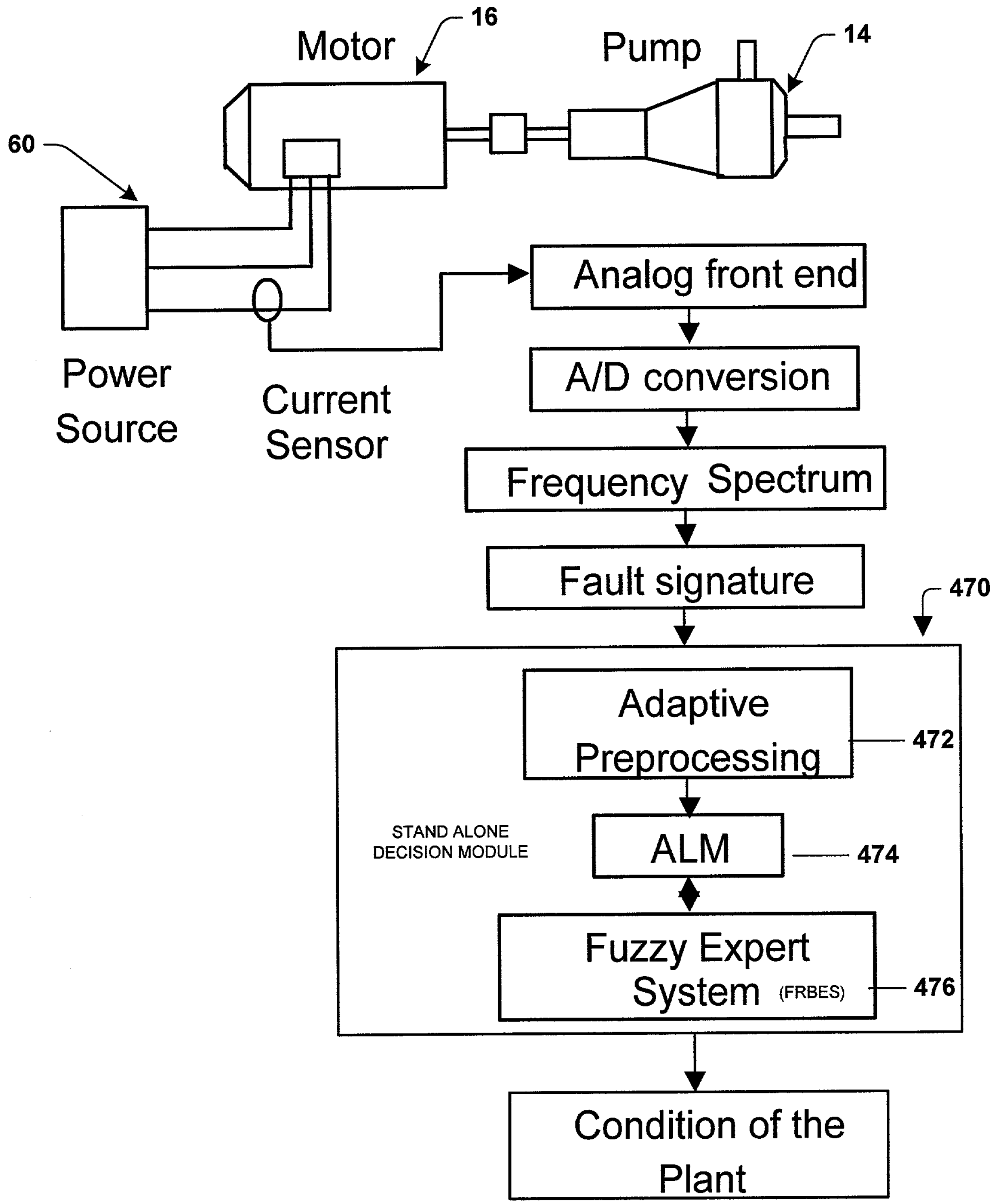

Motor
16
Pump
14
60
Power Source
Current Sensor
Analog front end
A/D conversion
Frequency Spectrum
Fault signature
470
Adaptive Preprocessing
472
STAND ALONE DECISION MODULE
ALM
474
Fuzzy Expert System (FRBES)
476
Condition of the Plant

Fig. 19

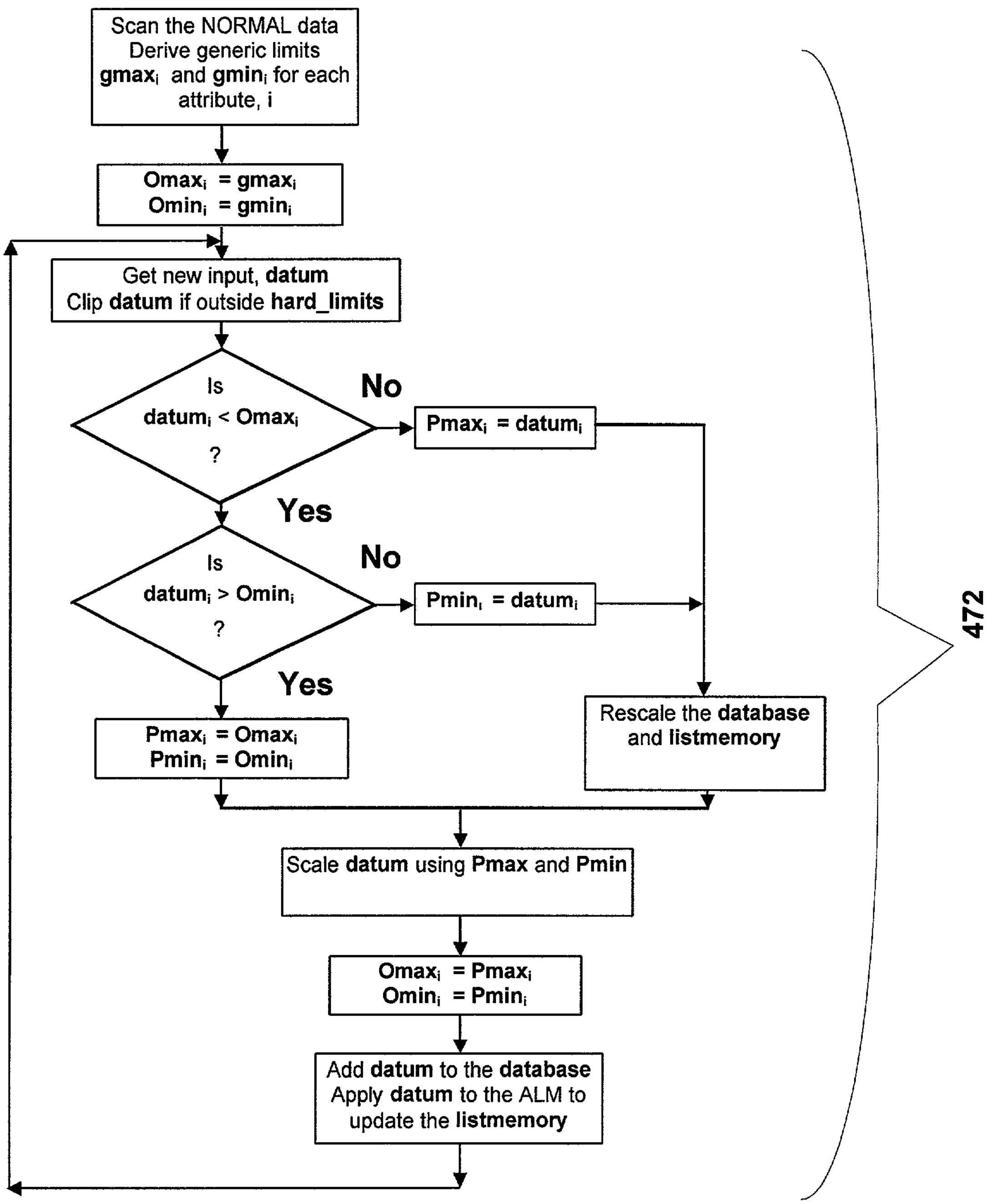

Scan the NORMAL data
Derive generic limits
gmaxi and gmini for each attribute, i
Omaxi = gmaxi
Omini = gmini
Get new input, datum
Clip datum if outside hard_limits
Is datumi < Omaxi ?
No
Pmaxi = datumi
Yes
Is datumi > Omini ?
No
Pmini = datumi
Yes
Pmaxi = Omaxi
Pmini = Omini
Rescale the database and listmemory
Scale datum using Pmax and Pmin
Omaxi = Pmaxi
Omini = Pmini
Add datum to the database
Apply datum to the ALM to update the listmemory
472

Fig. 20

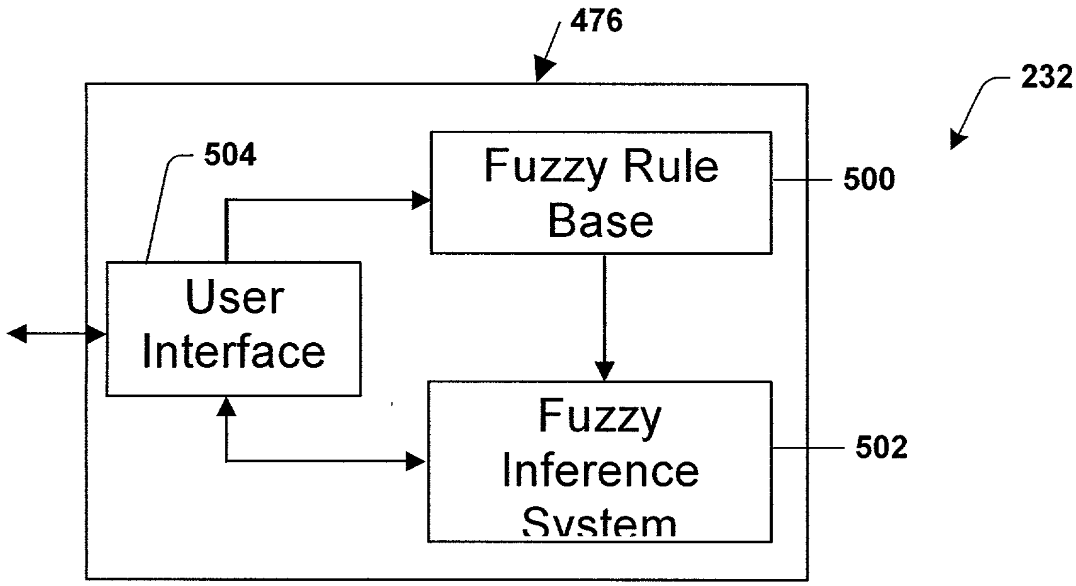

476
232
504
Fuzzy Rule Base
500
User Interface
Fuzzy Inference System
502

Fig. 21

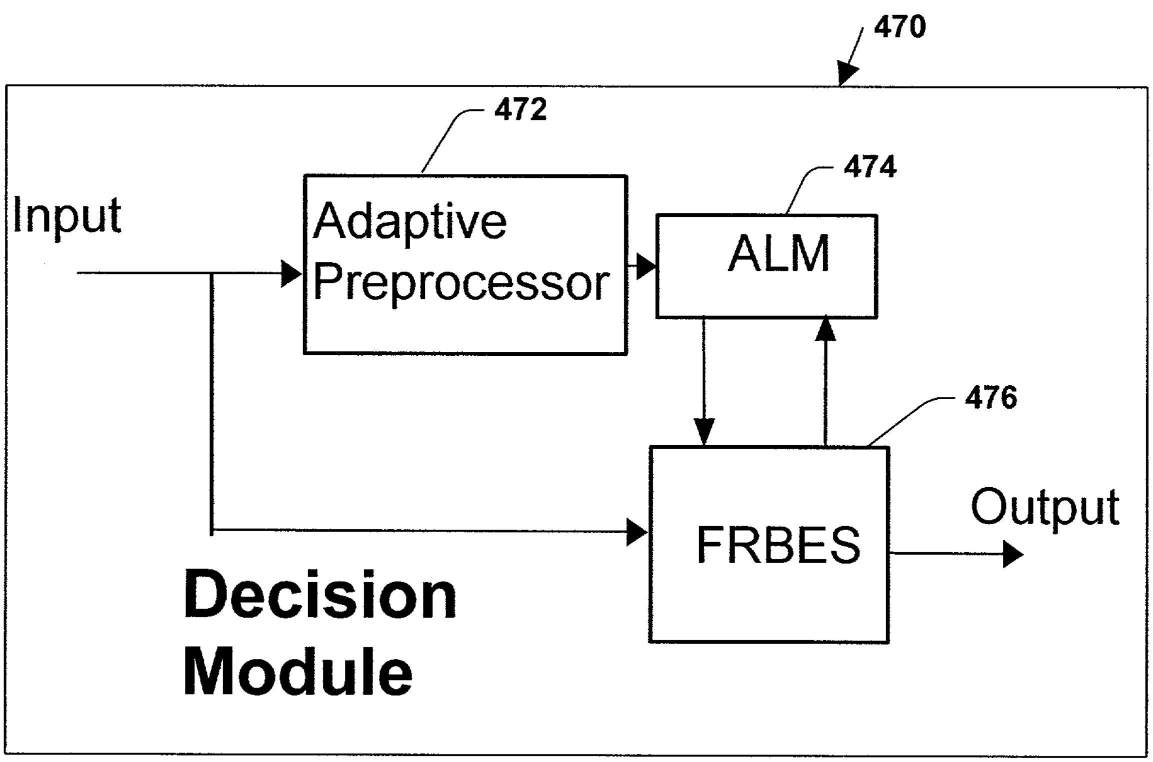

470
472
474
Input
Adaptive Preprocessor
ALM
476
Output
FRBES
Decision Module

Fig. 22

IF all the attributes are *NORMAL* **THEN** condition is normal

IF slip is *SLLO* and noise_2 is *HI* **THEN** condition is low-cav

IF noise_4 and noise_5 are *VERHI* **THEN** condition is sev-cav

IF noise_4 and noise_5 are *HI* **THEN** condition is sev-cav

IF FsAmp is *SLLO* and noise_5 are *SLHI* **THEN** condition is sev-cav

IF FsAmp is *LO* and noise_5 is *SLHI* **THEN** condition is sev-cav

IF FsAmp is *VERLO* and noise_5 is *SLHI* **THEN** condition is sev-cav

IF FsAmp is *SLLO* and noise_4 are *HI* **THEN** condition is sev-cav

IF FsAmp is *LO* and noise_4 is *HI* **THEN** condition is sev-cav

IF FsAmp is *LO* and noise_4 is *VERHI* **THEN** condition is sev-cav

IF FsAmp is *SLLO* and slip is *SLLO* and noise_4 is *NORMAL* and noise_5 is *NORMAL* **THEN** condition is low-block

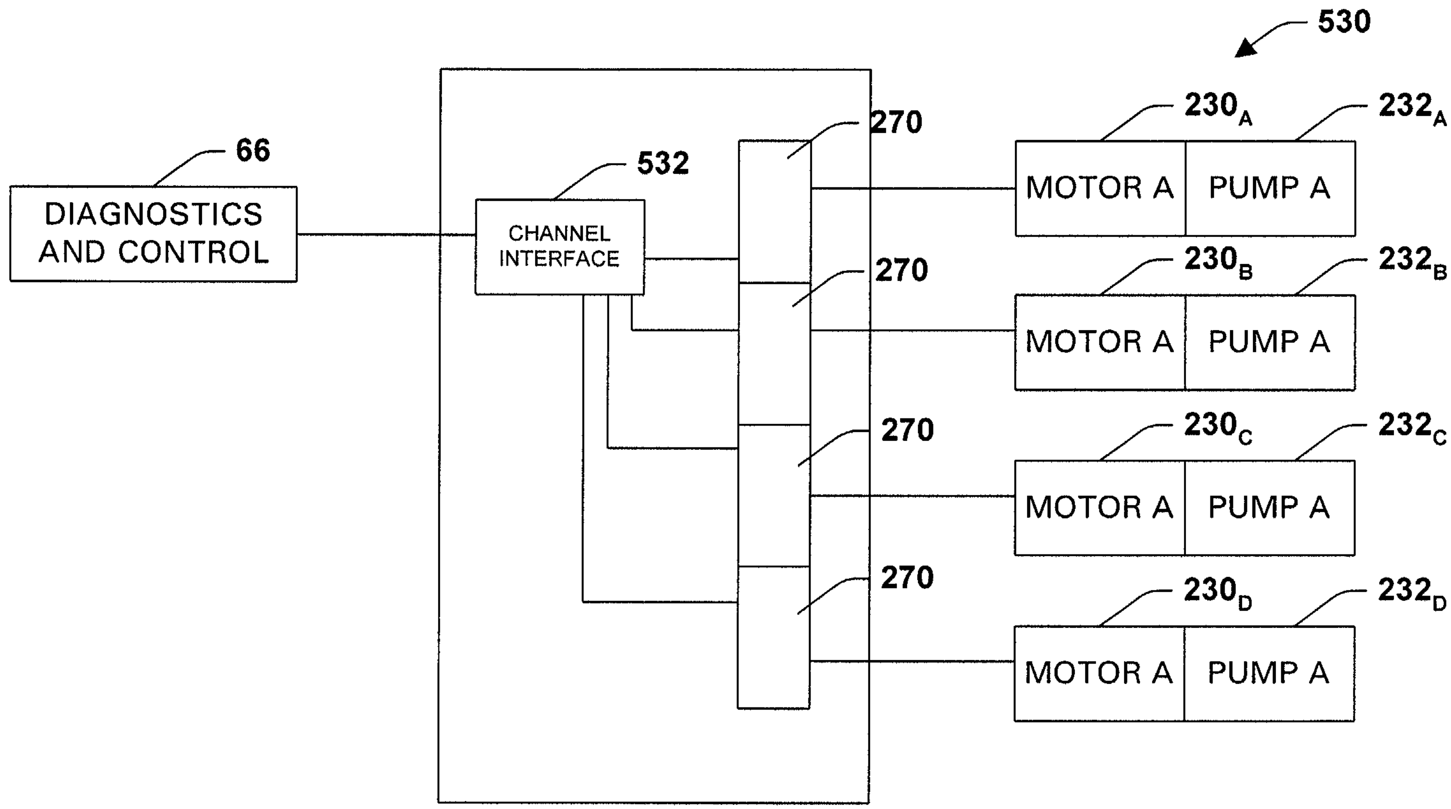
IF FsAmp is *LO* and noise_4 is *NORMAL* and noise_5 is *NORMAL* **THEN** condition is sev-block

IF slip and FsAmp are *VERLO* **THEN** condition is sev-block

IF FrAmp is *HI* **THEN** condition is impel-fault

IF framp is *VERHI* **THEN** condition is impel-fault

Fig. 23



530
66
DIAGNOSTICS
AND CONTROL
532
CHANNEL
INTERFACE
270
270
270
270
230_A
232_A
MOTOR A
PUMP A
230_B
232_B
MOTOR A
PUMP A
230_C
232_C
MOTOR A
PUMP A
230_D
232_D
MOTOR A
PUMP A

Fig. 24

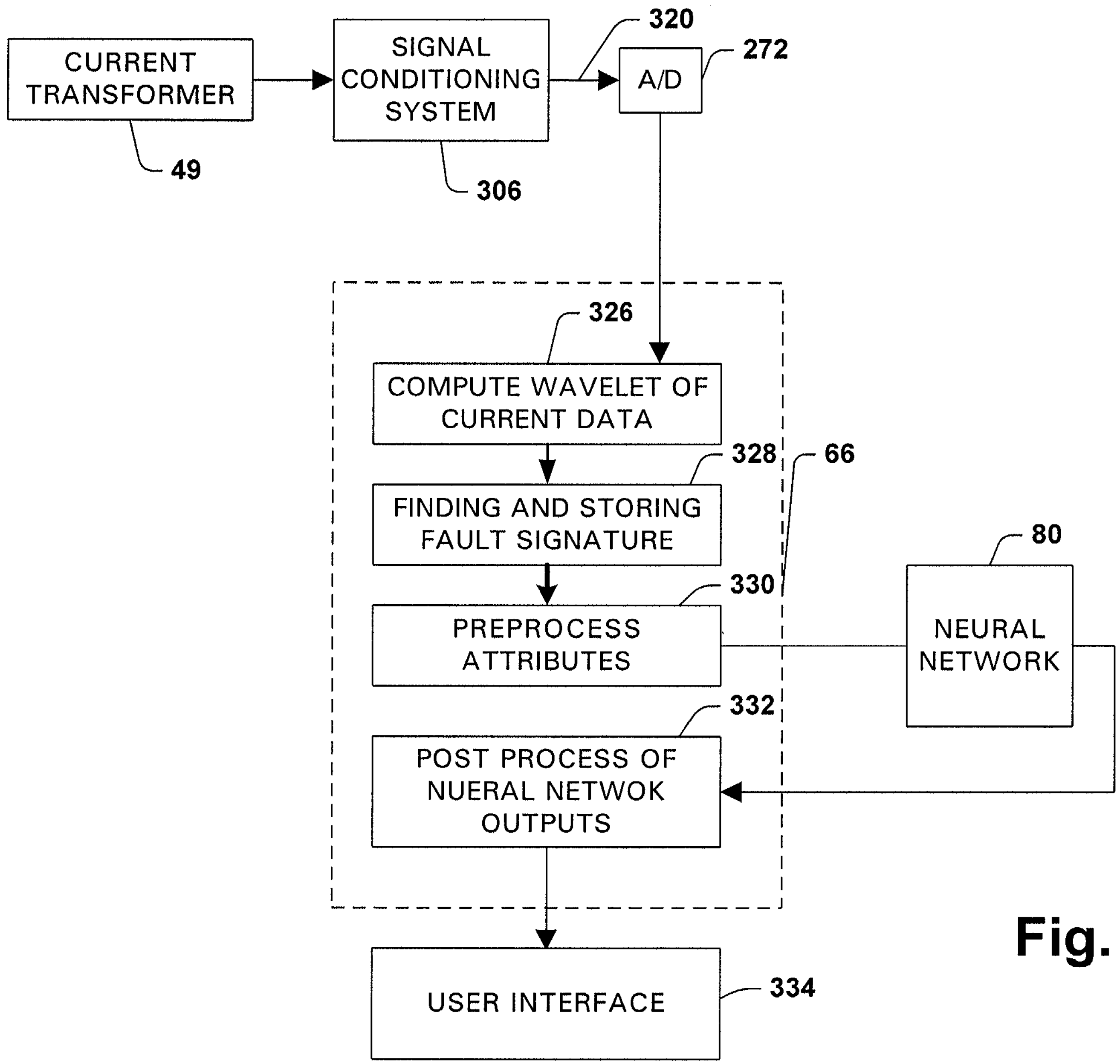

CURRENT TRANSFORMER
49
SIGNAL CONDITIONING SYSTEM
306
320
A/D
272
326
COMPUTE WAVELET OF CURRENT DATA
328
FINDING AND STORING FAULT SIGNATURE
66
330
PREPROCESS ATTRIBUTES
80
NEURAL NETWORK
332
POST PROCESS OF NUERAL NETWOK OUTPUTS
USER INTERFACE
334

Fig. 25

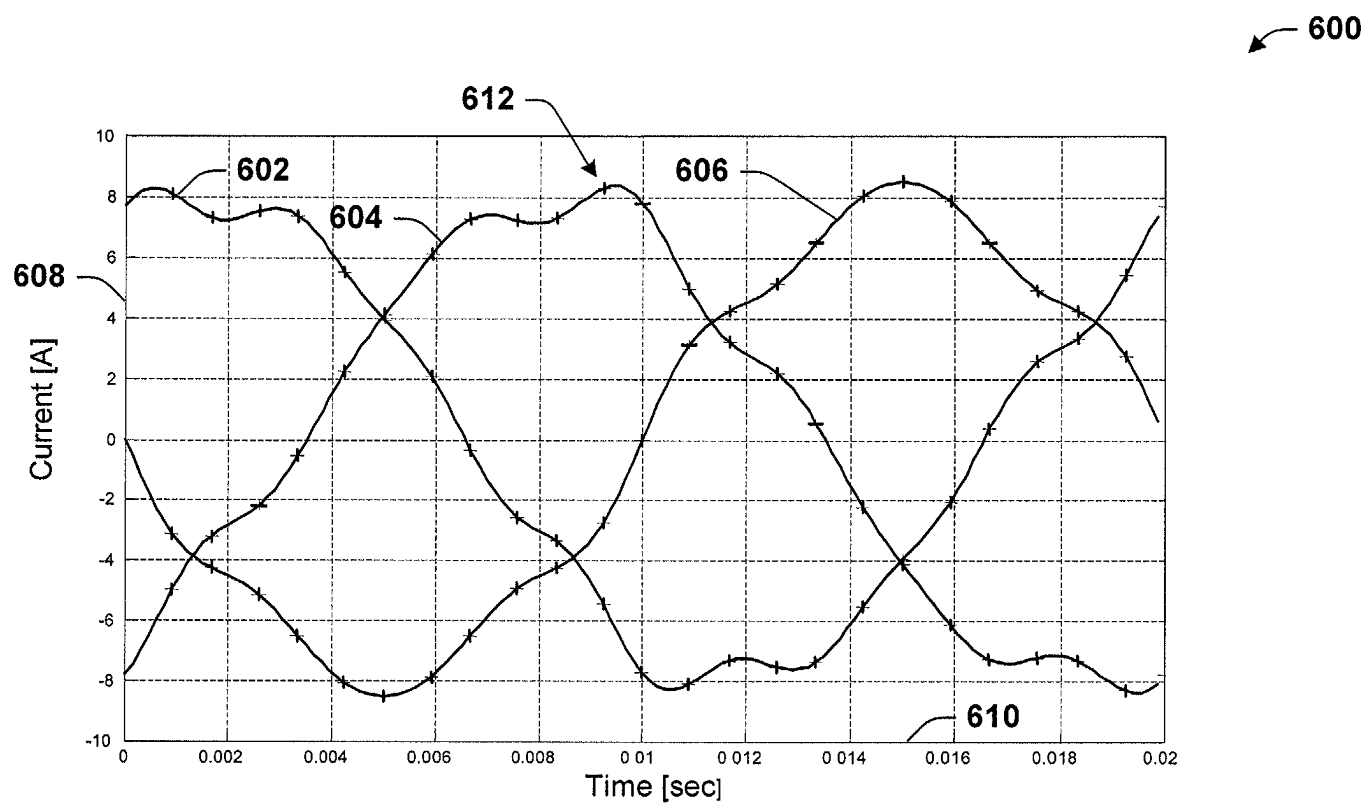

600
612
602
604
606
608
610
10
8
6
4
2
0
-2
-4
-6
-8
-10
Current [A]
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
0.016
0.018
0.02
Time [sec]

FIG. 26

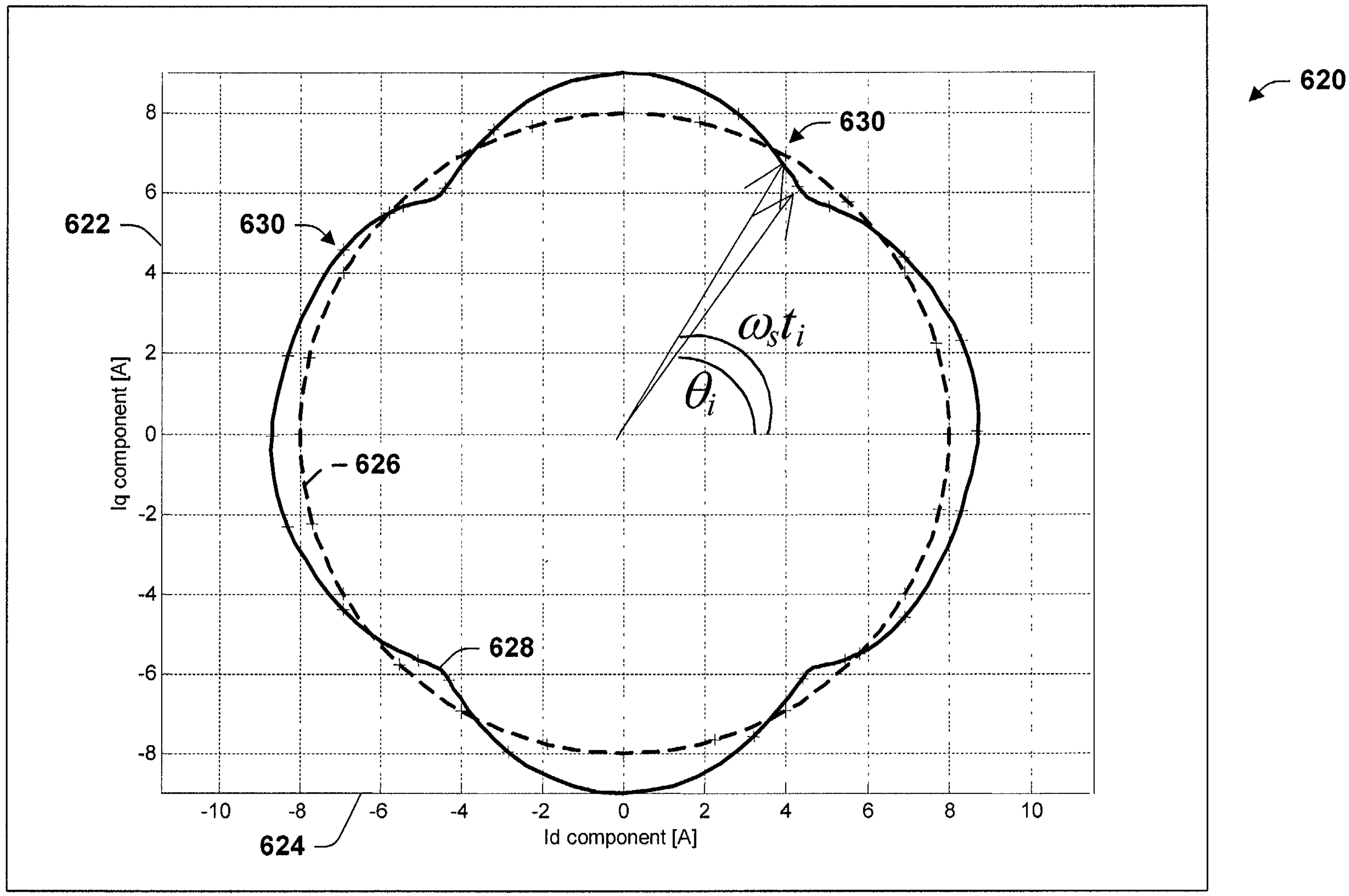
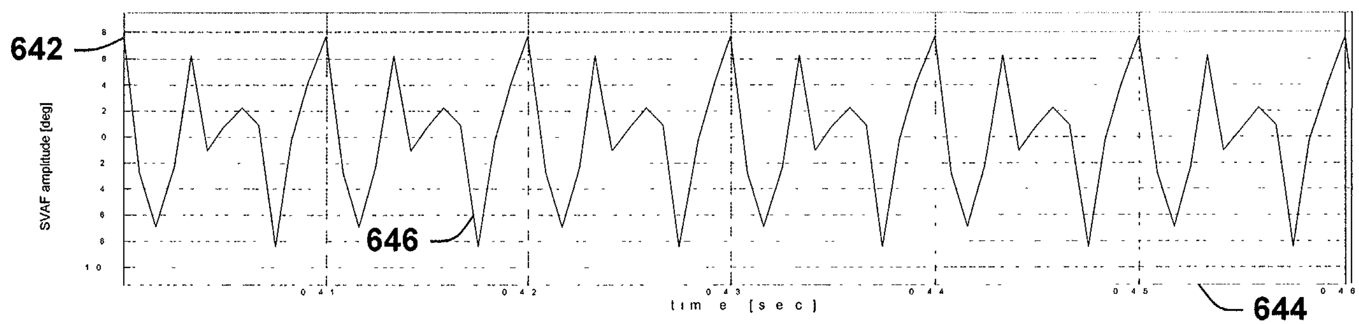
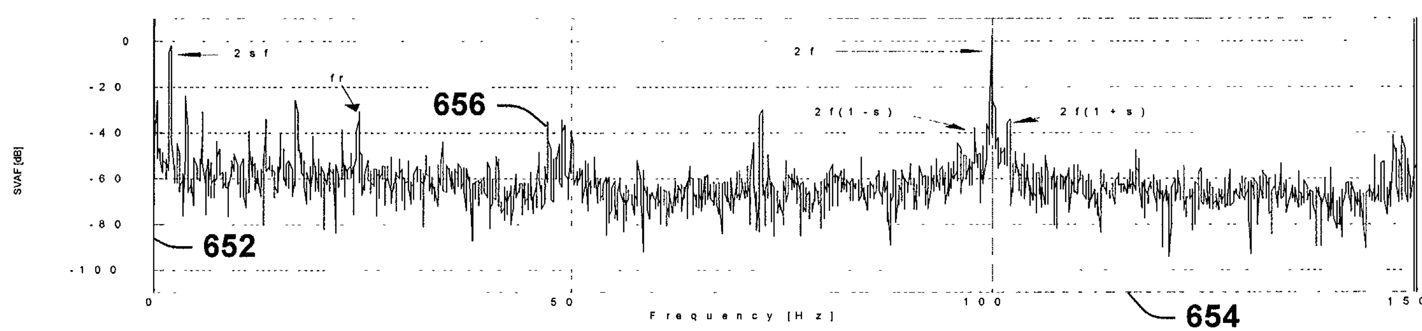

620
630
630
622
626
628
624
Iq component [A]
Id component [A]
$\omega_s t_i$
θ_i
8
6
4
2
0
-2
-4
-6
-8
-10
-8
-6
-4
-2
0
2
4
6
8
10

FIG. 27



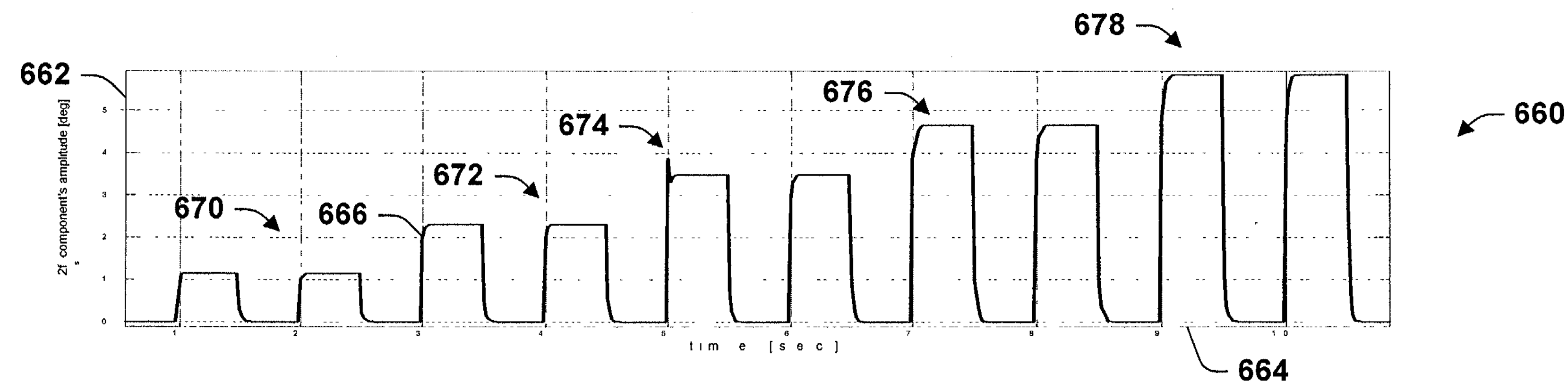
640
642
646
644
SVAF amplitude [deg]
time [sec]
0.41
0.42
0.43
0.44
0.45
0.46

FIG. 28



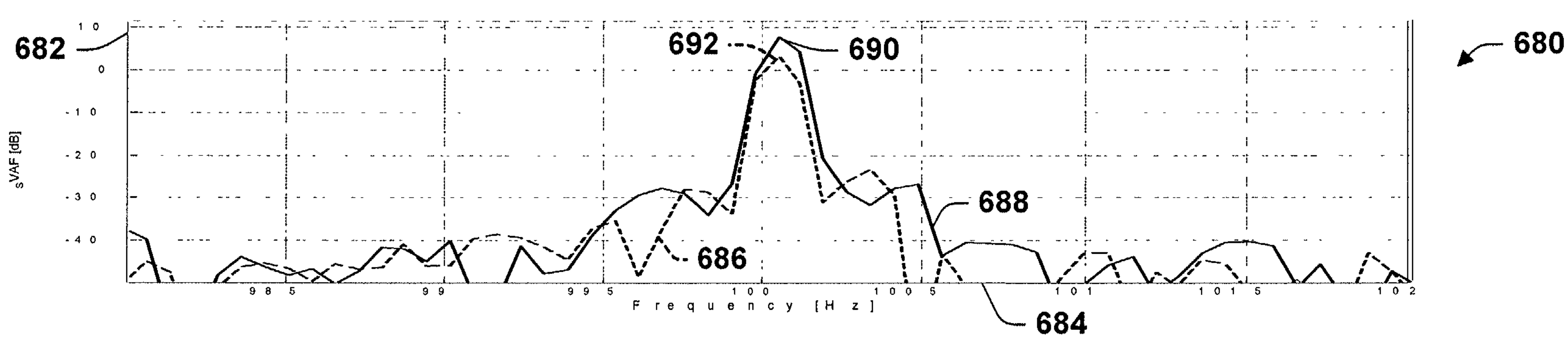
650
652
654
656
2sf
fr
2f
2f(1-s)
2f(1+s)
SVAF [dB]
Frequency [Hz]
0
-20
-40
-60
-80
-100
50
100
150

FIG. 29



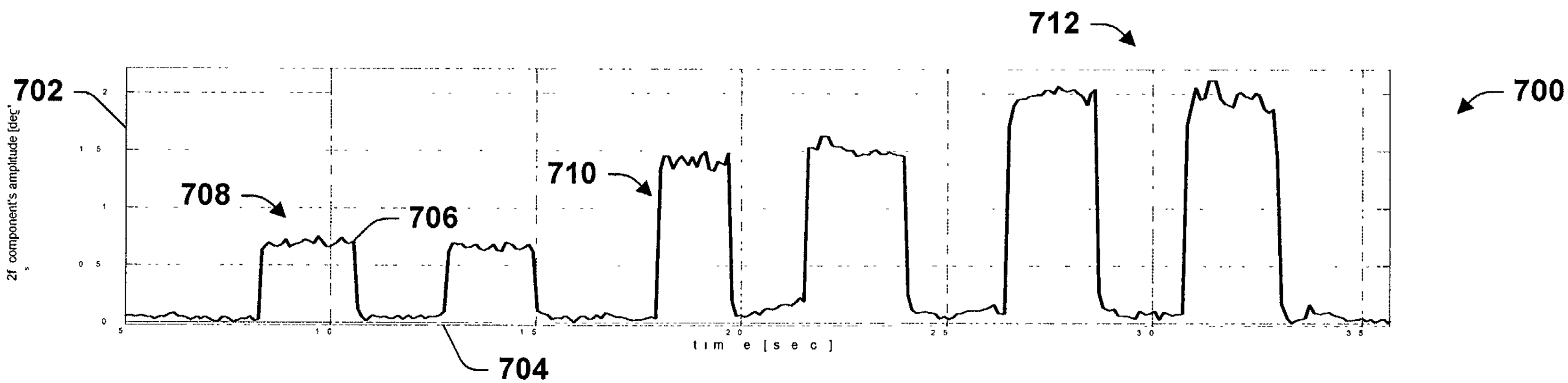
660
662
664
666
670
672
674
676
678
2f component's amplitude [deg]
s
0
1
2
3
4
5
6
7
8
9
10
time [sec]

FIG. 30



680
682
684
686
688
690
692
10
0
-10
-20
-30
-40
sVAF [dB]
98.5
99
99.5
100
100.5
101
101.5
102
Frequency [Hz]

FIG. 31



700
712
702
2f component's amplitude [deg]
710
708
706
704
time [sec]

FIG. 32

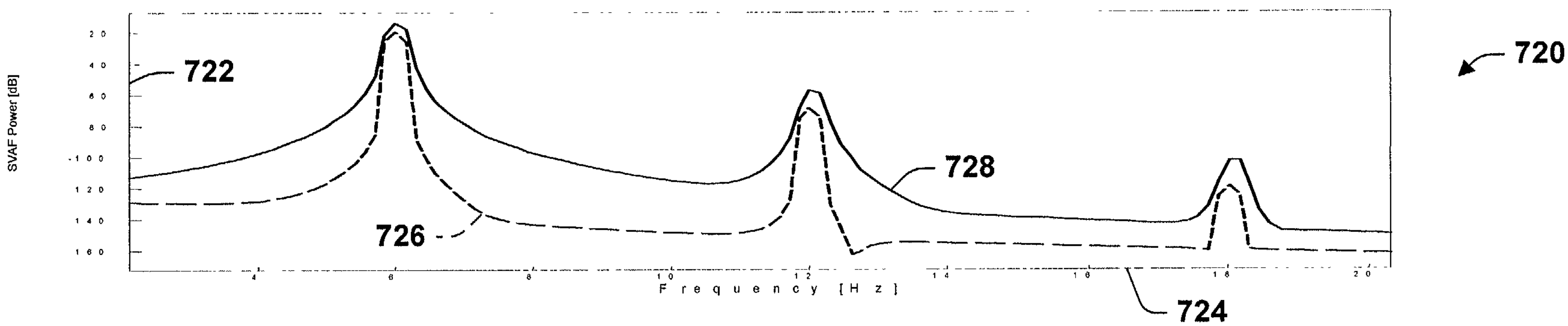

720
722
726
728
724
SVAF Power [dB]
Frequency [Hz]

FIG. 33

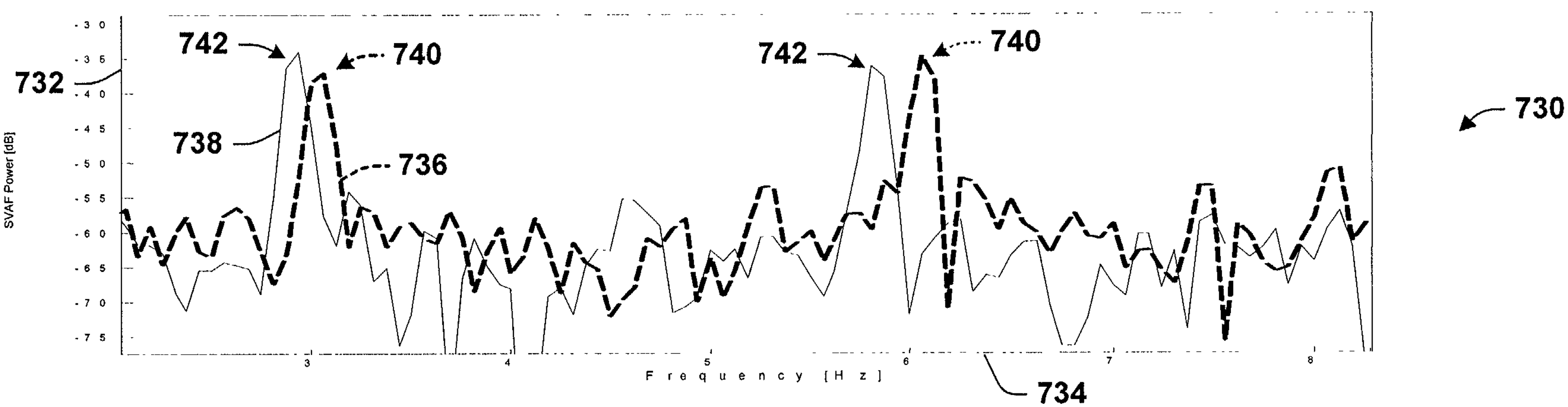

730
732
742
740
738
736
742
740
734
SVAF Power [dB]
Frequency [Hz]

FIG. 34

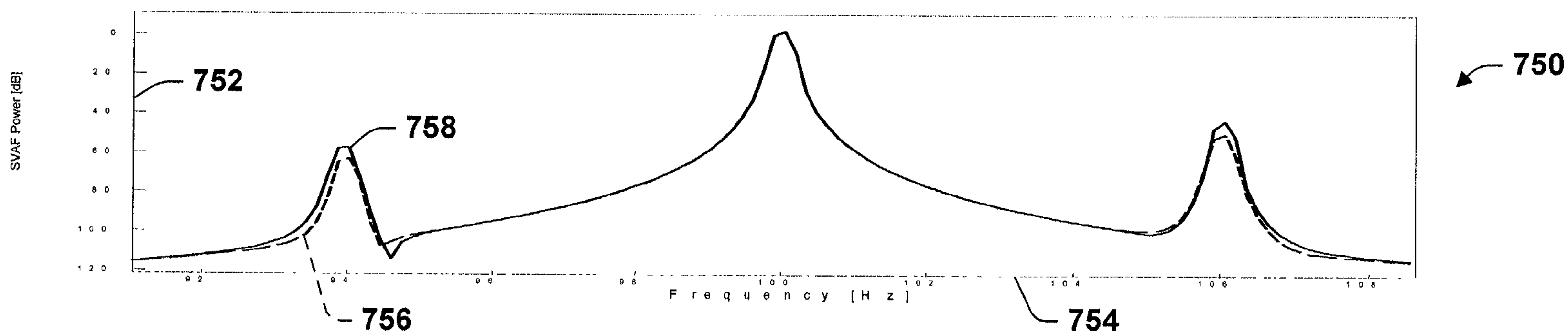

750
752
758
756
754
SVAF Power [dB]
0
20
40
60
80
100
120
92
94
96
98
100
102
104
106
108
Frequency [Hz]

FIG. 35

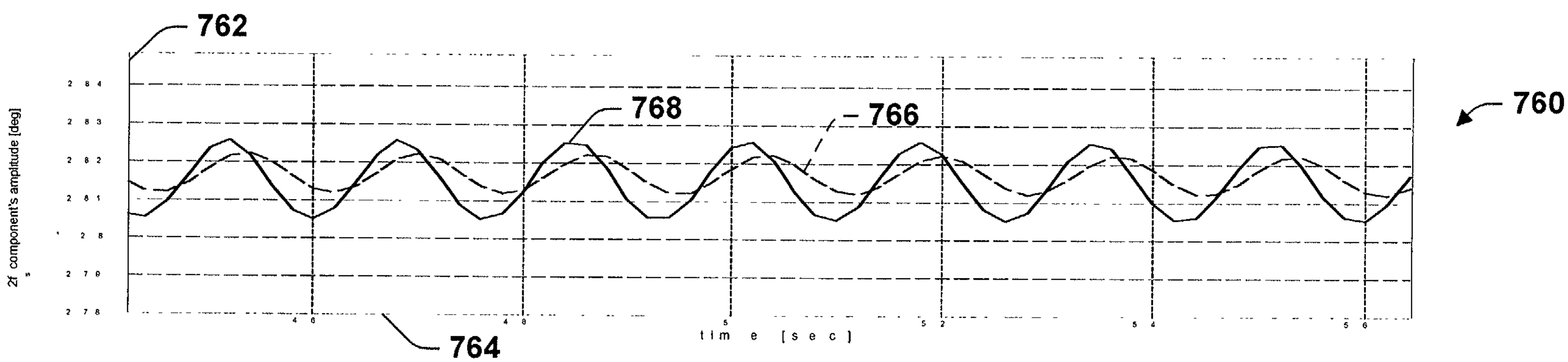
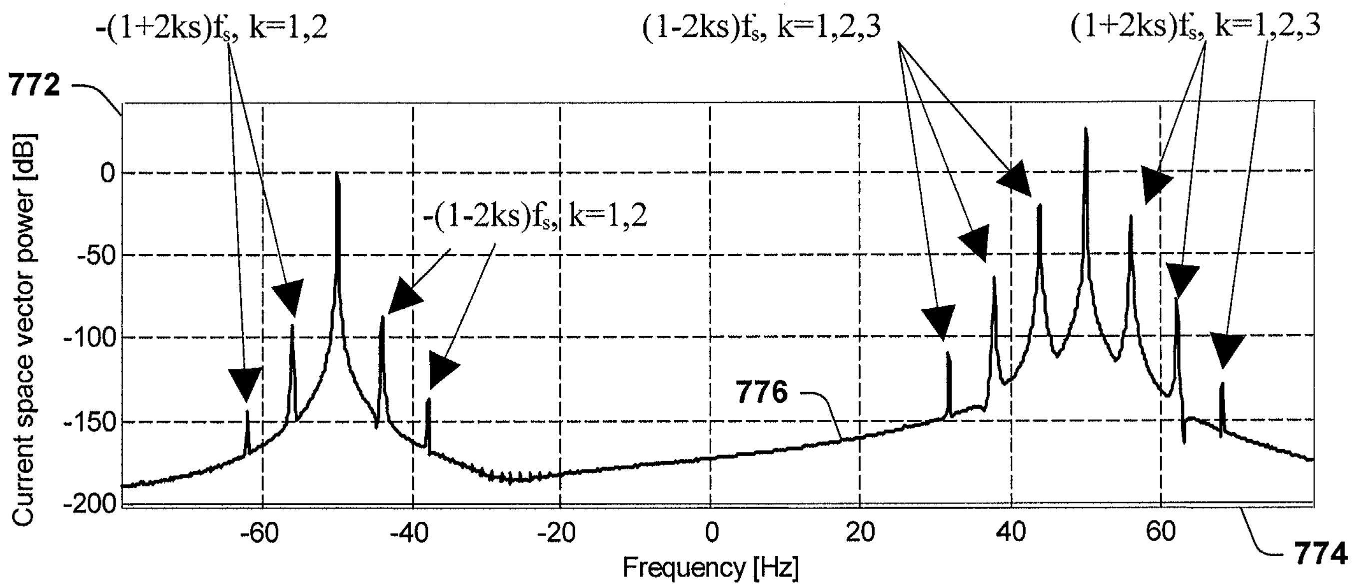
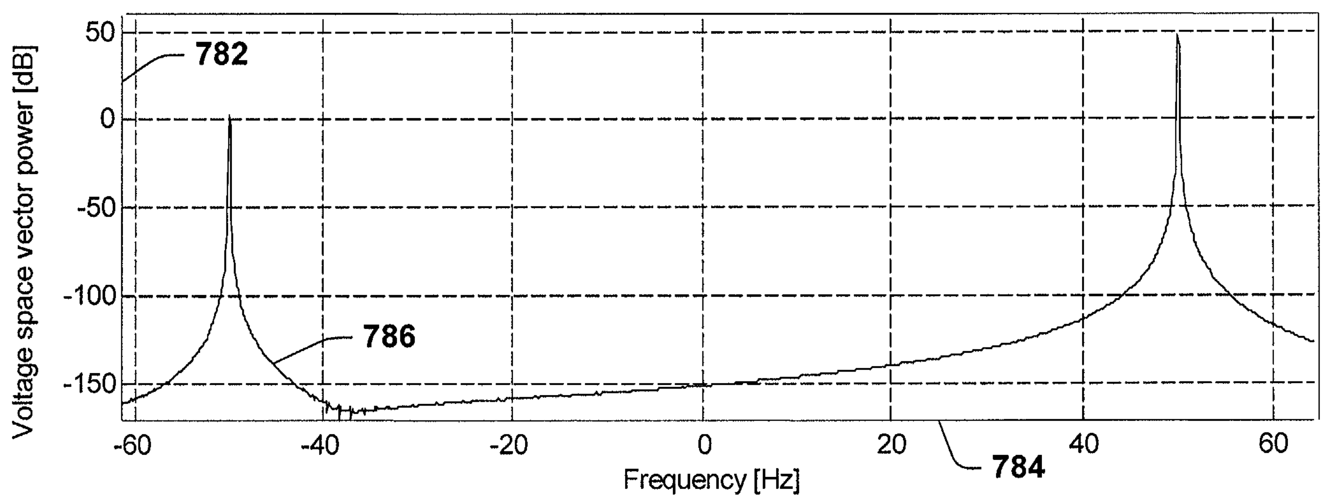

760
762
768
766
764
2f component's amplitude [deg]
284
283
282
281
28
279
278
46
48
5
52
54
56
time [sec]

FIG. 36



-(1+2ks)f_s, k=1,2
(1-2ks)f_s, k=1,2,3
(1+2ks)f_s, k=1,2,3
-(1-2ks)f_s, k=1,2
772
770
776
774
Current space vector power [dB]
0
-50
-100
-150
-200
-60
-40
-20
0
20
40
60
Frequency [Hz]

FIG. 37



782
780
786
784
Voltage space vector power [dB]
50
0
-50
-100
-150
-60
-40
-20
0
20
40
60
Frequency [Hz]

FIG. 38

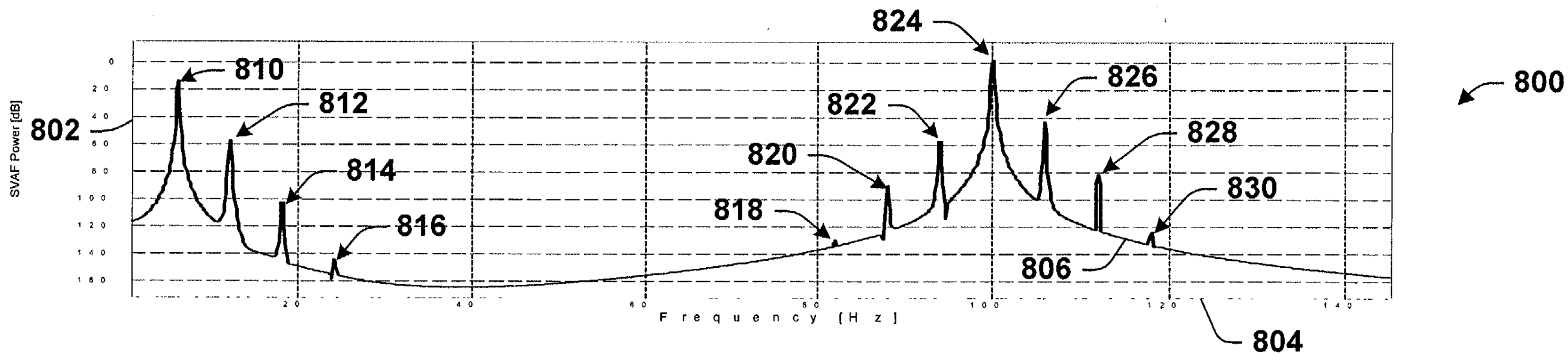

800
802
804
806
810
812
814
816
818
820
822
824
826
828
830
SVAF Power [dB]
Frequency [Hz]
0
20
40
60
80
100
120
140
160
20
40
60
80
100
120
140

FIG. 39

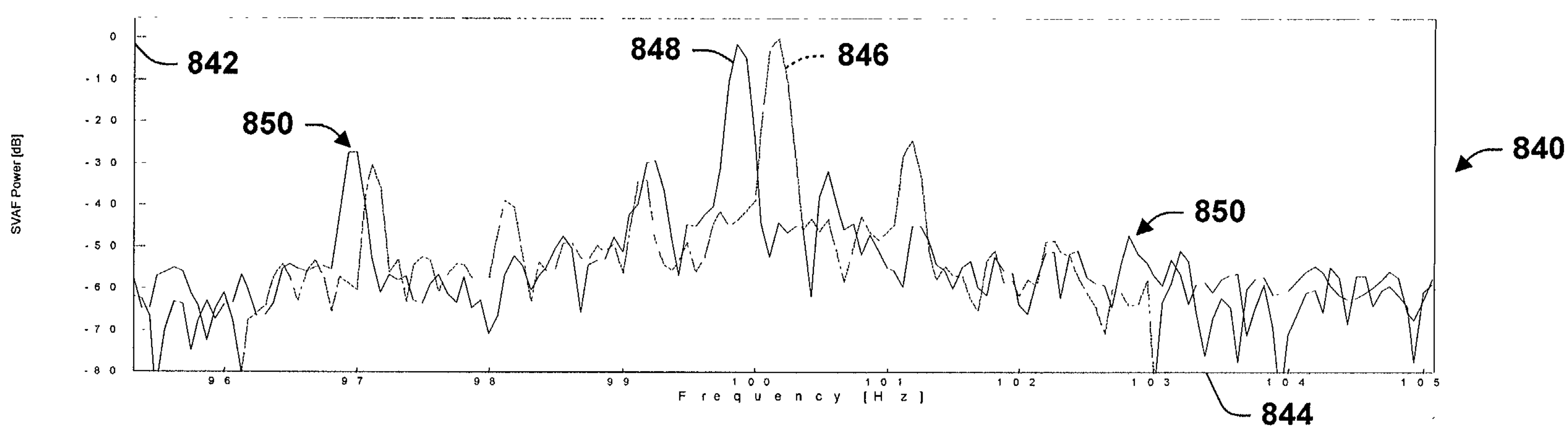
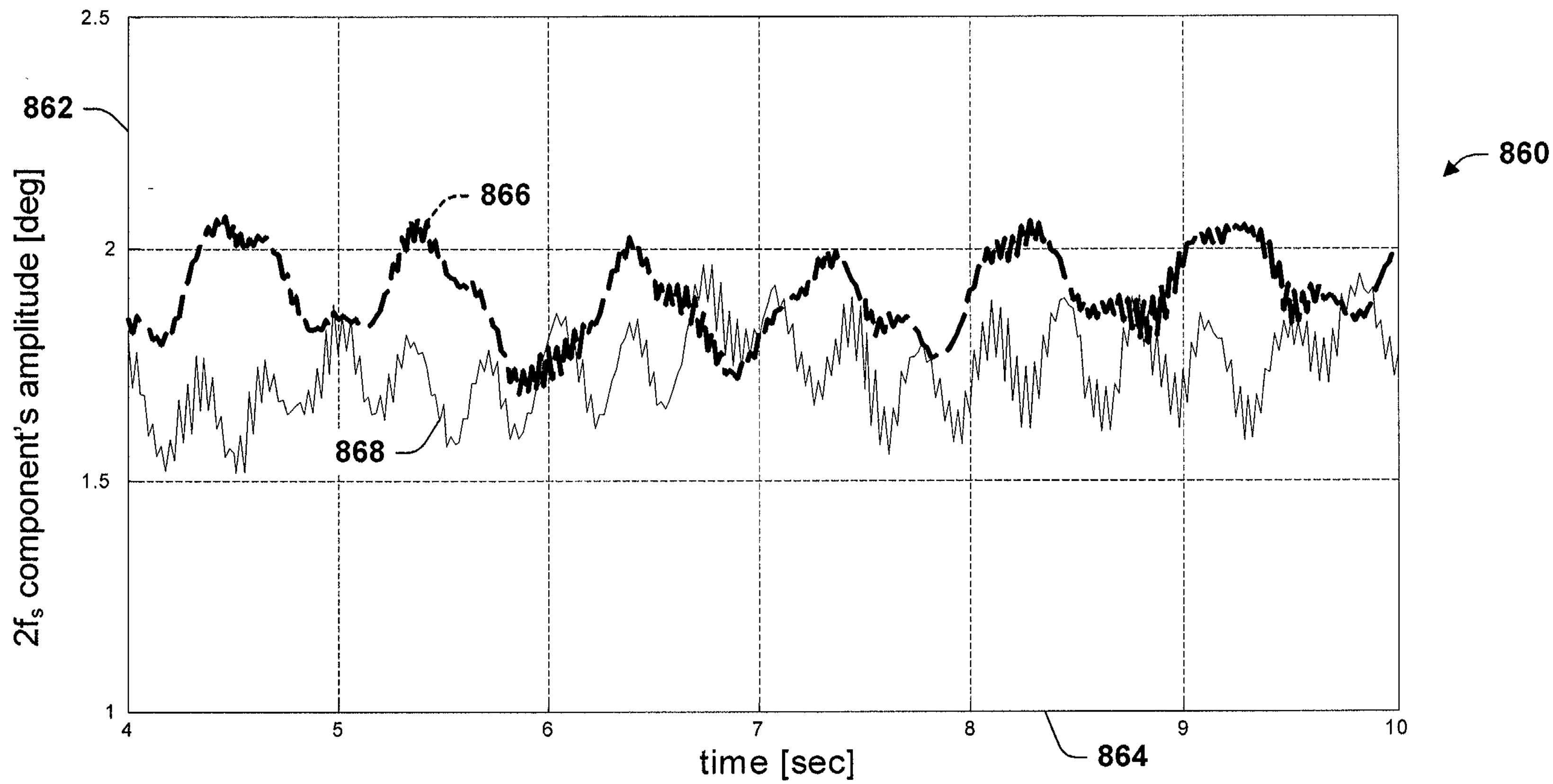

840
842
844
846
848
850
850
SVAF Power [dB]
Frequency [Hz]
0
-10
-20
-30
-40
-50
-60
-70
-80
96
97
98
99
100
101
102
103
104
105

FIG. 40



860
862
866
868
864
2.5
2
1.5
1
4
5
6
7
8
9
10
$2f_s$ component's amplitude [deg]
time [sec]

FIG. 41

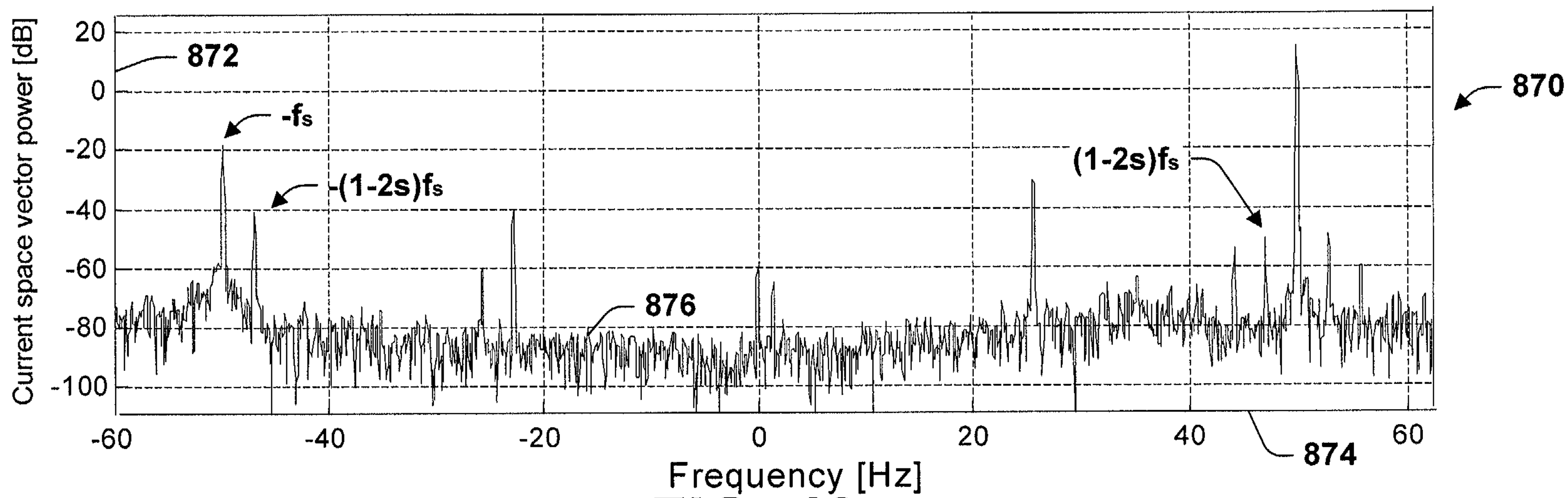

Current space vector power [dB]
20
0
-20
-40
-60
-80
-100
-60
-40
-20
0
20
40
60
Frequency [Hz]
872
-fs
-(1-2s)fs
876
(1-2s)fs
874
870

FIG. 42

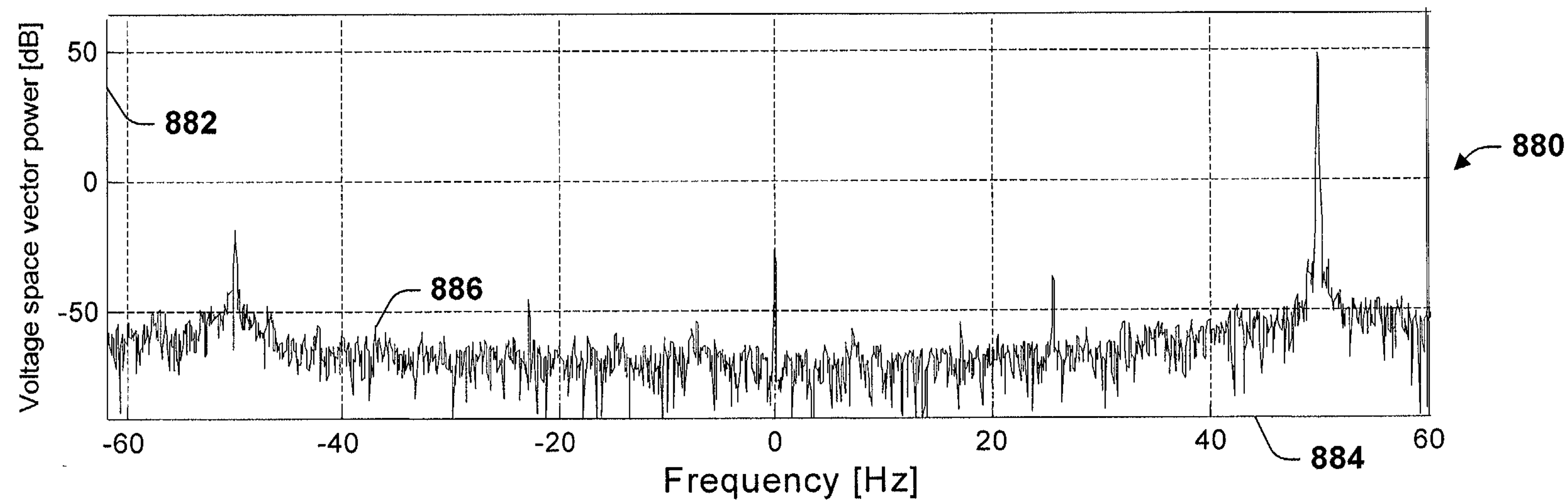

Voltage space vector power [dB]
50
0
-50
-60
-40
-20
0
20
40
60
Frequency [Hz]
882
886
884
880

FIG. 43

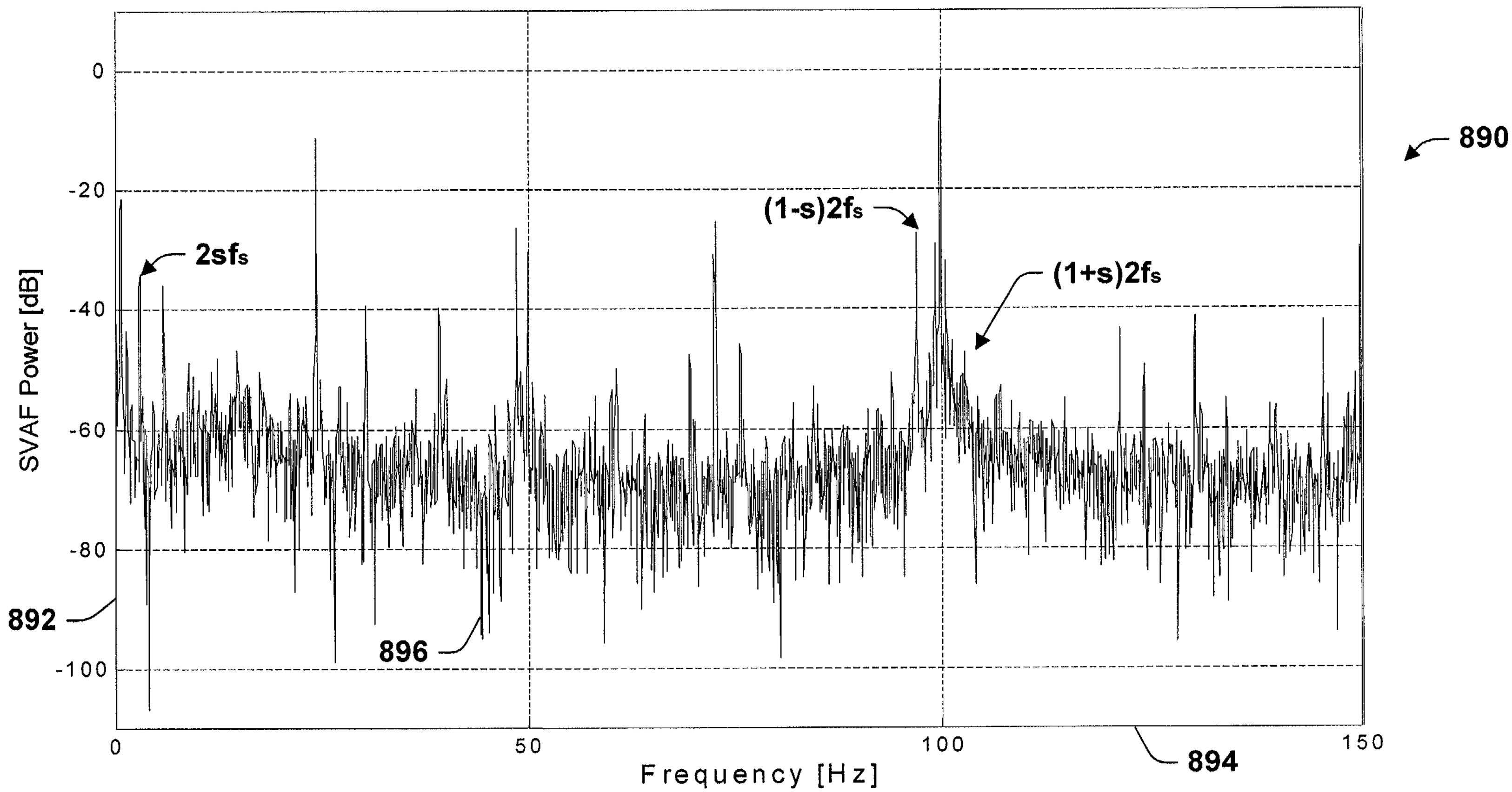

890
SVAF Power [dB]
0
-20
-40
-60
-80
-100
892
2sfs
(1-s)2fs
(1+s)2fs
896
0
50
100
150
Frequency [Hz]
894

FIG. 44